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Electrical power transmission and load analysis for field machines

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ELECTRICAL POWER TRANSMISSION AND LOAD ANALYSIS

FOR FIELD MACHINES

by

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Signature was redacted for privacy.

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Signature was redacted for privacy.

Dean of Graduate College

Iowa State College

1957

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INTRODUCTION

Development and Uses of Portable Electric Power Units for the Farm

The development of the portable electric power units which are available to the farmer today paralleled the electrification of the farmstead. Electrification of the farmstead brought about many changes in the daily routine on the farm. Many conveniences were made possible by the availability of electrical energy and the farmer soon became dependent upon it for performing many of the daily chores which were previously performed by hand. Soon this dependence developed to such an extent that a power failure always resulted in inconvenience and in some cases serious damage. In those installations where a prolonged power failure meant a disaster, consideration was given to standby generators for use during a prolonged power failure.

The early standby generators were usually 5 kw or less in size and were driven by a two- or four-cylinder air cooled engine. The generators were designed to deliver 120-volt, single-phase a-c power which could be used to light the farmstead and furnish power for those installations which must be kept going. As the electrical load on the farm increased, so did the size of the standby units available to the farmer.

The early standby generators were stationary units and were not used to any great extent as portable units. Although they could be moved, the excessive weight prohibited their movement in most cases. As a result, the standby generator was a specialized piece of equipment which was used only a very short time during the year. In most cases, the farmer could not justify the purchase of the equipment because the stationary standby generator was not used to any great extent.

The advent of the larger size farm tractor and the need for a standby generator brought about the development of the portable standby generators. The early portable standby generators were mounted on wheels and attached directly to the drawbar for transport around the farmstead. The generator was driven from the pto (power-take-off) of the tractor. Thus, portable electric power was available on the farm.

Although these units usually were purchased for use as standby power sources, the farmer soon realized their value for supplying electric power beyond the reaches of the power line. Electric tools such as welders, drills and saws could be used not only in the farm shop but anywhere on the farm.

The development in 1953 of the tractor-mounted generator brought about a portable standby power source which opened up new possibilities for the design of farm machines. The system can be used for any of the jobs mentioned and also used for the application of electric power for the drive and control of field machines. The tractor-mounted generator may be used as an electrical coupling to drive field machines such as combines, haybalers, mowers and other field machines.

Some investigators (14) have compared the performance of machines operated with electrical couplings with the performance of auxiliary engine driven machines. This is not a proper comparison because the auxiliary engine introduces power into the system above that supplied by the tractor engine. The electrical coupling is simply an alternative to the pto (power-take-off) coupling as a means of transmitting power from a tractor engine to a drawn or mounted machine.

Design Considerations

Efficiency

Losses occur in the generator, motor and the mechanical connection of the generator to the engine drive shaft; and the overall efficiency of the coupling is the product of the efficiencies of the component parts. The mechanical connection of a generator to an engine drive typically would have an efficiency of about 95 per cent. According to Shoults, D. R., Rife, J. C. and Johnson, T. C., (17) the efficiency of the average three-phase induction motor (8-10 hp, 1800 rpm) is 85 per cent at rated load. Assuming a generator efficiency of 85 per cent, an overall efficiency of about 68 per cent can be expected for the electrical coupling.

Maleev and Hartman (13) indicate that an efficiency of 96 to 98 per cent can be expected for properly aligned double universal joints. The pto is connected to the engine by one gear mesh; therefore, an overall efficiency of 94 to 96 per cent can be expected for the mechanical coupling. When one compares the 94 to 96 per cent with 68 per cent energy transfer, the question arises as to the real advantage of the electrical coupling. On first thought, one is apt to conclude that the electrical coupling is not a desirable coupling for connecting the tractor to the field machine since it transmits power less efficiently than the standard mechanical coupling. A further investigation reveals that the usefulness of the electrical coupling cannot be determined solely by its overall efficiency. The following discussion serves to point out the necessity of considering other factors.

Burrough (5) indicated that as much as 20 to 30 per cent of the power required to operate a 7-foot combine is lost as friction in the various drives of the machine. In studying these figures, it should be noted that all the power must be transmitted through a single drive and then distributed throughout the machine by v-belts and gears. With the electrical coupling, the power may be distributed to any part of the machine without any appreciable increase in the losses. By breaking the machine load down into several load groups and using more than one electric motor, part of the v-belts and gears can be eliminated. Since most of the losses occur in the various drives, a considerable reduction in the machine losses could be expected. Therefore, machine simplification and reduction in machine losses could make the electrical coupling compare more favorably with the pto couplings when used on machines such as combines.

Motor application

The motor or torque supplied by an electric motor is determined to a large extent by the load requirements. The speed at which the power requirements of the load are satisfied is determined by the characteristics of both the motor and the load. According to Fitzgerald, A. E. and Kingsley, C. (8), the operating speed of an electric motor is fixed at the speed at which the power or torque that the motor can furnish is equal to the power or torque that the load can absorb.

Although the motor requirements are determined to a large extent by the load, it must be remembered also that the generator output of any portable system is limited and for this reason may require a motor of special design. The design of the motor must be such that it will develop the greatest possible power from the generator output. Lukens (12, p.11) said:

> The farm machine load is characterized by having sudden high peaks because of varying and adverse field conditions. It is, of course, desirable to have the motor "carry through" these peaks without stalling or requiring the operator to ease off in some manner. This means that the highest possible locked rotor torque and particularly breakdown torques, when operating from the generator, are desirable. A motor with the proper slip to drive the load under normal conditions should be selected. Its inherent design should be good so that the torque per ampere "efficiency" is as high as practicable. The impedance of the motor should then be adjusted by varying the number of turns, or other parameters, so the greatest possible KVA is drawn from the generator and transmitted to the motor.

Lukens also states that it is necessary to make sure that the motor operates properly at average loads and light loads.

Because of the limited output of the portable system, selection of the proper motor size becomes very important. Although the motor demands vary according to the load, the greatest efficiency will be obtained from a motor when it is operating at its rated load. If the capacity of the motor is greater than needed, a greater portion of the energy consumed is converted to heat and other losses. According to Wagner (19), doubling the motor size on fluctuating loads often results in more than doubling the watt hours of electricity consumed.

In motor selection, it also should be remembered that most electric motors will respond to a high momentary overload without damaging the motor. For example, Lukens (12) indicates that the 7.5-hp motor developed for farm machines has a maximum momentary output of 15 hp and can run continuously at 10 hp for the life of the farm machine. This represents a 200 per cent momentary overload and 130 per cent continuous overload. According to Wagner (19), the momentary overloads must exceed 250 per cent before the induction motor reaches pull-out torque and stops.

Objectives of the Study

The development of a tractor-mounted generator might be envisioned as the beginning of a new era in the design of power transmission from tractor to field machine. With portable electric power available for the control and operation of the various components of field machines, the replacement of mechanical or hydraulic coupling may be a reality.

Although a basic unit has been assembled by others (14) and successfully field tested to a limited degree, many problems remain to be worked out. As indicated earlier, one of the major problems is that of the determination of the proper generator and motor requirement for maximum power transmission between generator and motor. The limited capacity of a tractor-mounted generator makes maximum power transfer a necessity if the system is to be successful on the larger machines such as combines.

For the reasons outlined above, a study was initiated to investigate the problems associated with electrical drives on farm machines. The study was designed to determine generator and motor requirements and to determine what modifications are necessary in the design of farm machines for electrical coupling application. For the study, the following objectives were set up:

1. To gain an insight into the problems associated with electric power transmission of field machines.
2. To determine the factors governing the generator and motor requirements.
3. To determine design criteria for electrical couplings for field machinery.
4. To determine design requirements for agricultural machinery to make it more suitable for electric drives.

INVESTIGATION

To accomplish the above objectives, an electrical coupling was used to drive a combine. Performance data were obtained for the electrical coupling and the pto coupling under a variety of loading conditions. Field studies were made in wheat, oats and soybeans. Loading studies also were made by feeding the combine from a conveyor belt. A complete description of the tests conducted is given later in the report.

Equipment

Electrical coupling

The electrical coupling consisted of the generator and motors and all wiring and controls between the two. Both single- and multiple-motor couplings were used. To clarify terminology, the following definitions are given:

Single-motor coupling - A 7.5 motor driving entire machine.

Multiple-motor coupling (9.5 hp) - A 7.5-hp plus a 2-hp motor driving the machine.

Multiple-motor coupling (10.5 hp) - A 7.5-hp plus a 3-hp motor driving the machine.

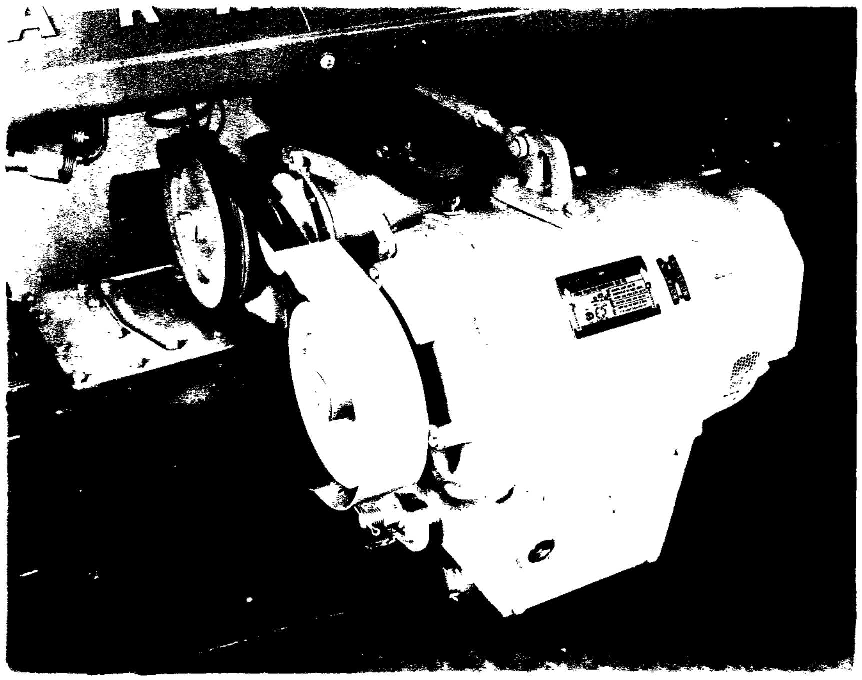
Multiple-motor coupling (12.5 hp) - A 7.5-hp plus a 3- plus a 2-hp motor driving the machine.

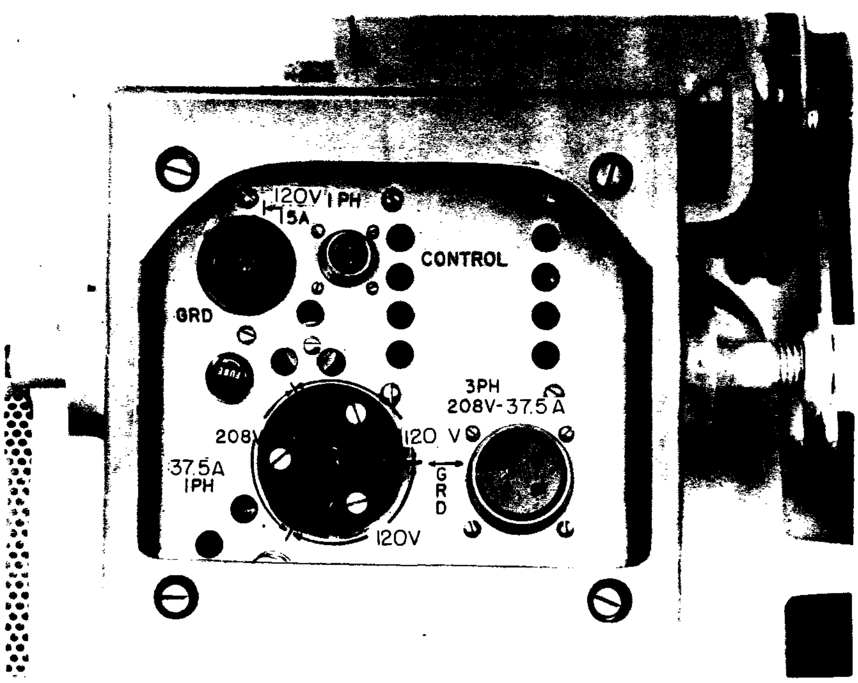
The generator is a 12.5-kw, 208-volt, 3-phase, 60-cycle, 2-pole, 3600-rpm, 4-wire, revolving-field alternator. This unit is manufactured by the General Electric Company and marketed by the International Harvester Company under the trade name, "Electrall". A plot of the no load voltage versus field current for the generator is shown in Figure 43 in Appendix B. The generator is equipped with a voltage regulator, overload protection and an exciter which are all integrally mounted. The generator is connected directly to the tractor as shown in Figure 1.

As shown in Figure 2, the generator delivers a variety of power combinations. Sockets are available for 115-volt, single-phase power; and 208-volt, 3-phase power. The 208-volt, 3-phase plug is the common AN type. This plug is used for all 3-phase operations of the generator and can be used for 120- or 120/208-volt single-phase operations by using a plug that connects only two or three of the contacts. The common AN connector has a threaded collar which eliminates the possibility of the plug's falling out due to vibration. The 120- and 120/208-volt single-phase outlets may be used for powering most of the ordinary electrical tools or appliances found around the farm. The small socket for 120-volt single-phase power is protected by a 20-amp fuse. The three-prong, 120/208-volt, single-phase outlet accepts any standard 30- or 50-amp caps which are commonly known as "stove connectors". All

Fig. 1. Close-up view showing the method of connecting the tractor to the generator (courtesy International Harvester Company).

Fig. 2. Close-up view of the panel of the Electrall generator (courtesy International Harvester Company).




120V 1PH
15A
CONTROL
GRD
3PH
208V-37.5A
208V
120 V
37.5A
1PH
GRD
120V

large single-phase apparatus can be powered from the 120/208-volt socket. This would include relatively large single-phase motors, arc welders and stoves.

A connection diagram of the generator is shown in Figure 3. Excitation is furnished by a small generator in conjunction with a static type voltage regulator. Lukens (12, p.7) describes the excitation circuit as follows:

> The voltage control circuit or "regulator" is actually a "compounding" scheme. A current transformer is connected in one AC line, and the secondary output is rectified by a static rectifier and fed into the exciter field circuit. The voltage on the exciter field comes from the exciter armature in series with the transformer-rectifier combination, so that the exciter field current, and also the generator field current, are increased by increased AC current. This increased field current tends to counteract armature reaction and other internal drops in the generator so that it gives high peak outputs for motor starting and to carry high intermittent motor torques, without the necessity of carrying excessive field currents at light and normal loads ... A normally closed relay is incorporated in the circuit until the exciter voltage has built up to a pre-determined value, when the relay opens. This assures rapid voltage build up, and "snappy" motor starting.

The generator is protected against overloads by two separate units. A thermal device with a push button re-set is used to protect the generator against a sustained overload. The thermal device can be re-set after time has been allowed for it to cool off. In addition to the thermal protection, three 50-amp, time-delay fuses (see connection diagram) are used to protect the generator in event of a short circuit in

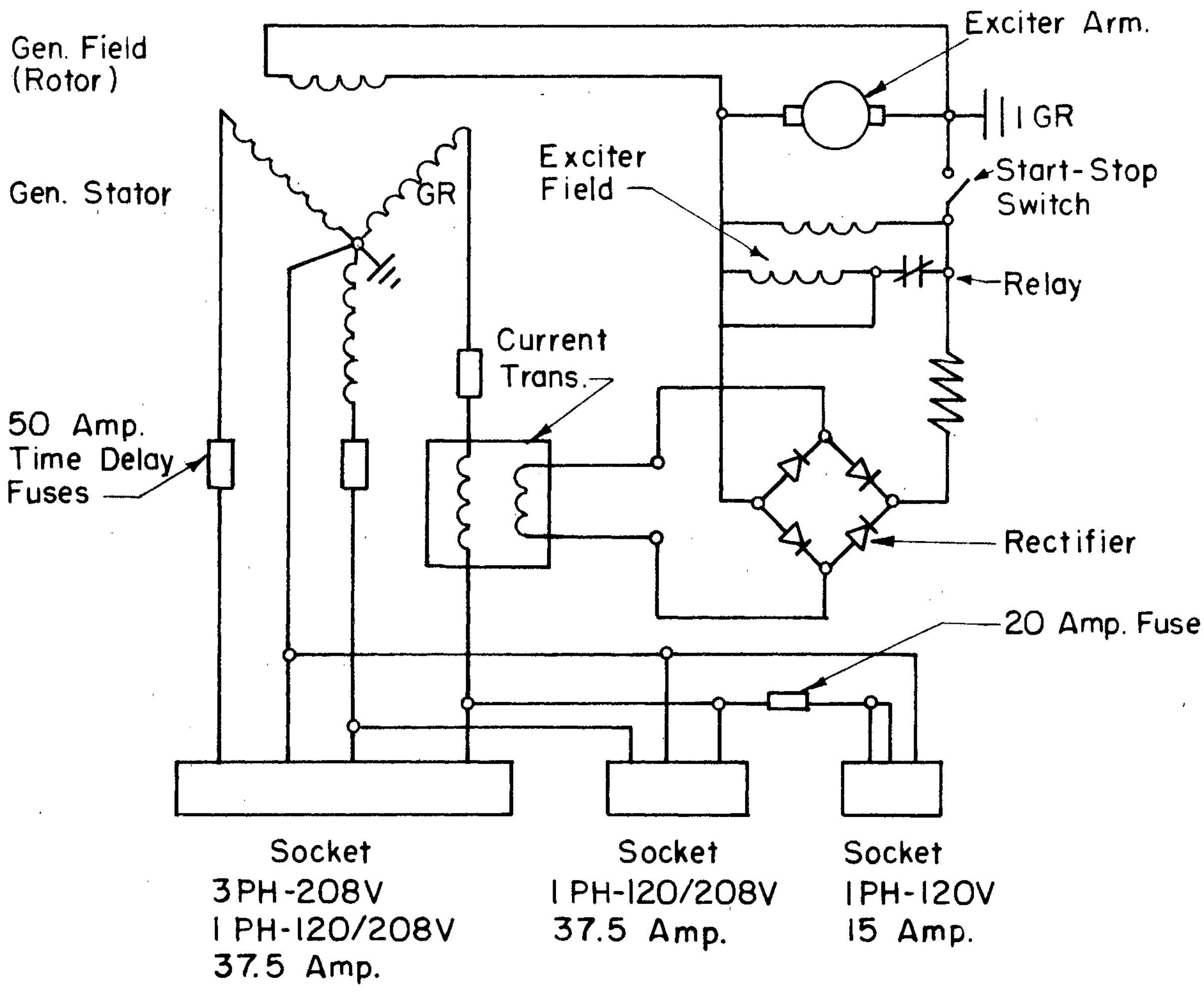


Fig. 3. Connection diagram of the Electrall generator (modified from Lukens (12)).

the load or output cable.

The motors used in the study were made available by the General Electric Company and each motor was identified as "Farm Machine Motor" on the name plate. The motors were 208-volt, 3-phase, 60-cycle, 4-pole, 1800-rpm, low-slip, squirrel-cage induction motors. The allowable temperature rise was 105 degrees C. Performance characteristic curves for each motor are presented later in the report.

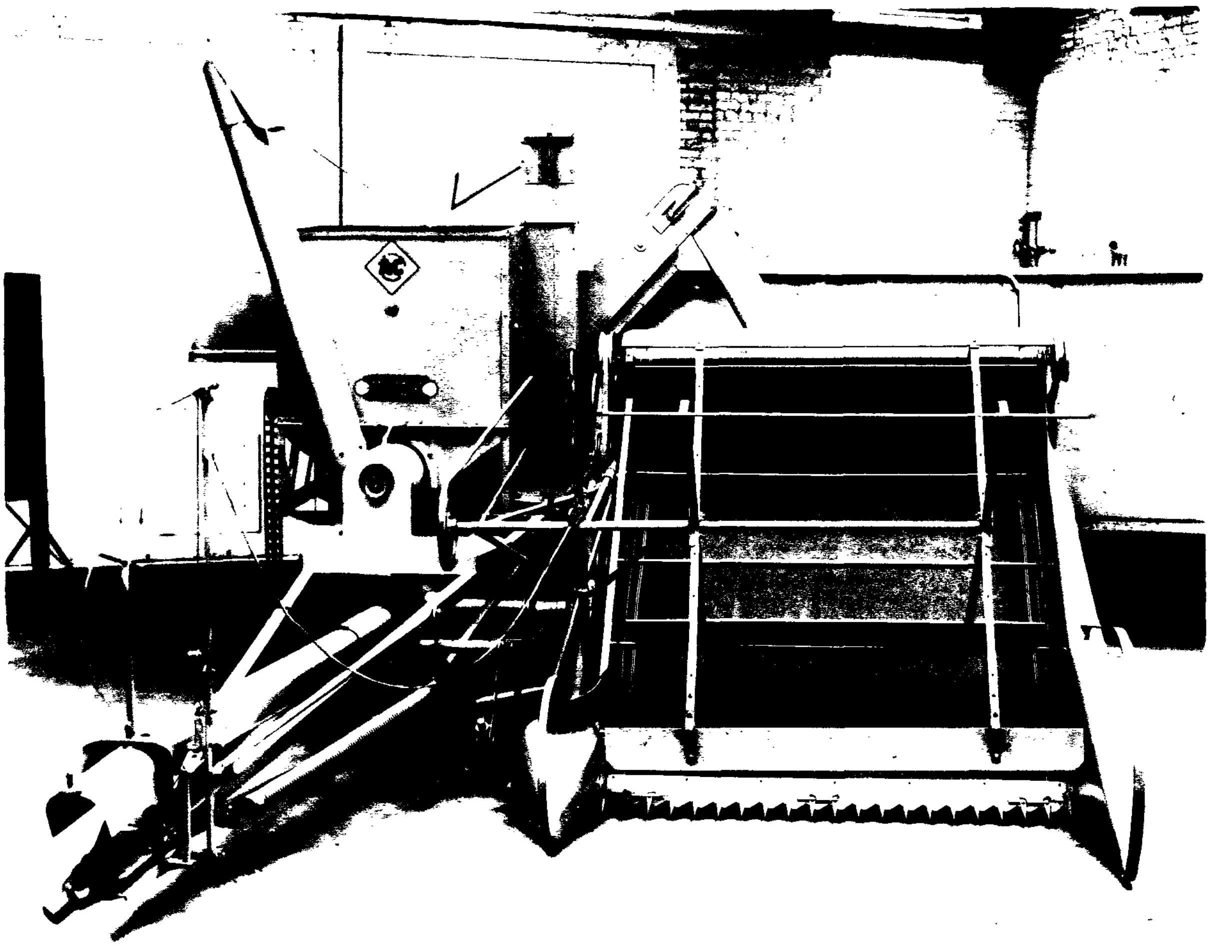
Combine

The combine was a Model 60 Allis-Chalmers. The machine may be used as direct cut machine or it may be equipped with a windrow pickup attachment. Figure 4 shows a front end view of the machine equipped for direct-cut combining. The combine may be driven by the pto or it may be equipped with an auxiliary engine.

The material is cut, elevated and fed directly into the cylinder. The feeding mechanism consists of the lower and upper canvas which directs the material into the cylinder. The lower canvas does all the elevating of the material from the knife to the cylinder. The upper canvas floats on the incoming material and helps to smooth out the material and direct it into the cylinder.

The machine has a 5-foot threshing cylinder. Eight rubber-face, spiral cylinder bars make up the cylinder as

Fig. 4. Front view of the Model 60 Allis-Chalmers combine equipped for direct cut combining (courtesy Allis-Chalmers Mfg. Company).



shown in Figure 5. Threshing takes place between the rubber-faced cylinder bars and the two rubber-block concaves and a rubber covered threshing plate as shown in Figure 6. Adjusting brackets are located on each end of the cylinder for changing the clearance between cylinder bars, concaves and threshing plate. A variable-speed v-belt drive is used for changing the cylinder speed to suit the conditions of the crop.

The material leaves the cylinder and enters the cleaning and separating unit. The cleaning and separating unit consists of the straw rack, sieves, elevators and fan. Figure 7 shows the arrangement of the various components which make up the cleaning and separating unit.

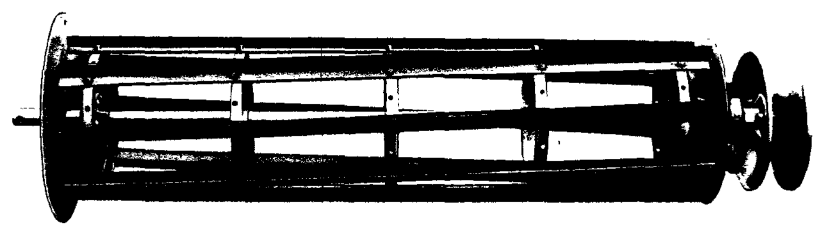
Combine power train. The combine power train was modified so that the machine could be driven by the pto coupling, the single-motor coupling, the multiple-motor coupling (9.5 hp), the multiple-motor coupling (10.5 hp) and the multiple-motor coupling (12.5 hp).

A schematic representation of the possible drive combinations is shown in Figure 8. All motors were connected to the drives as shown. Speed reduction from the motors was accomplished by proper selection of pulleys.

A large pulley was mounted on the front of the gear box so that power could be introduced into the system by the 7.5-hp motor. The pulley was keyed to a short shaft which was

Fig. 5. Close-up view showing the construction of the combine cylinder (courtesy Allis-Chalmers Mfg. Company).

Fig. 6. End view of the cylinder showing the cylinder bars and rubber-block concaves (courtesy Allis-Chalmers Mfg. Company).



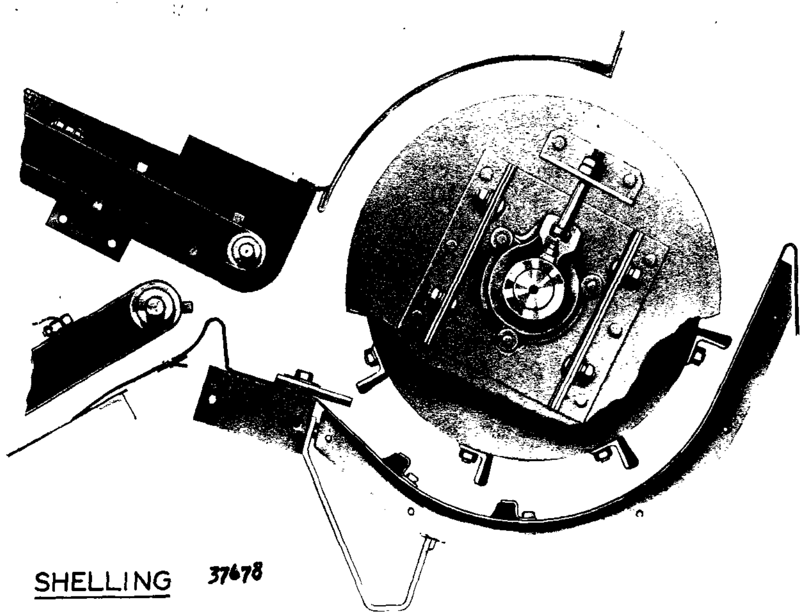
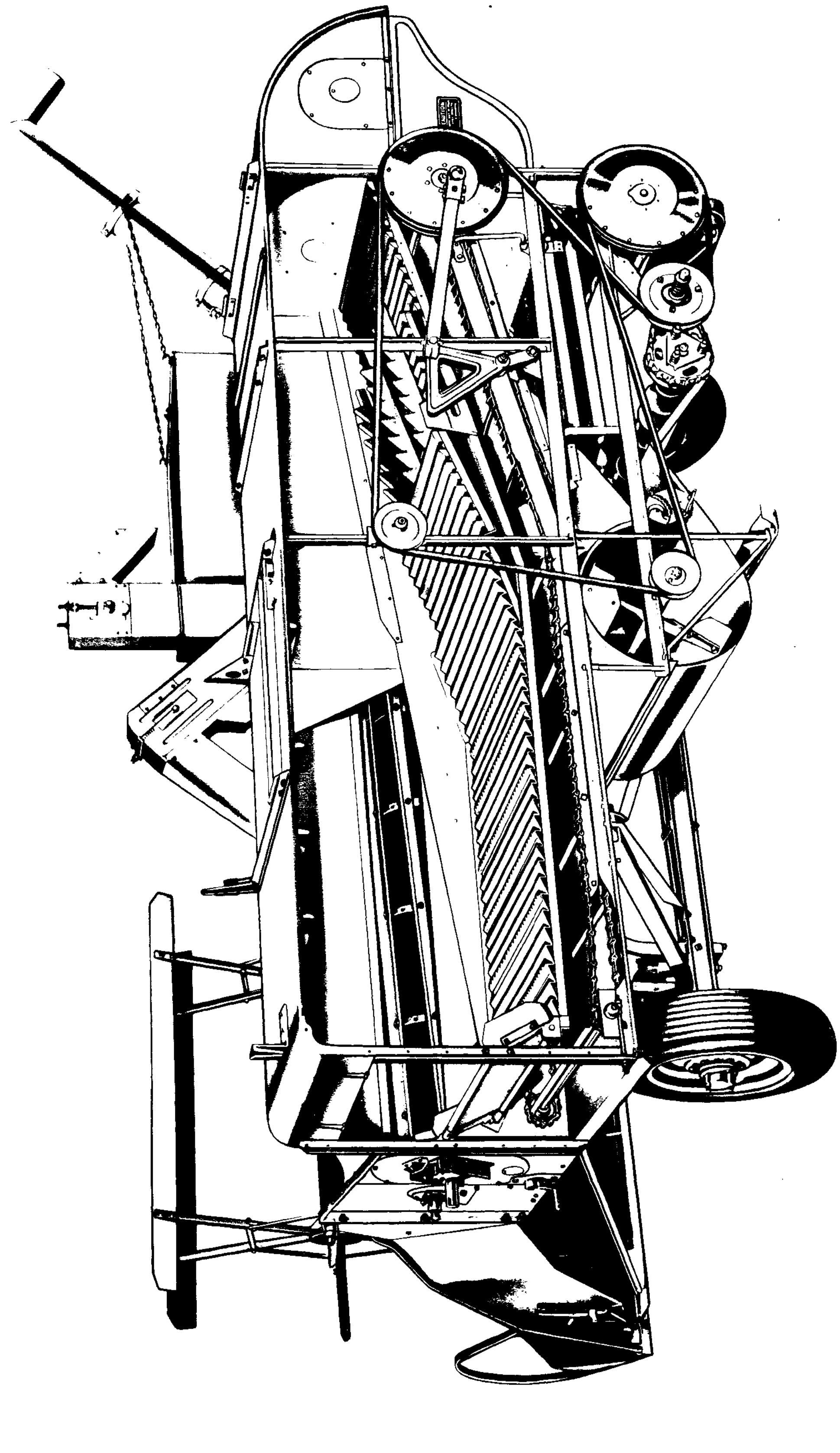

SHELLING
37678

Fig. 7. Cross section of the combine showing the arrangements of the cleaning and separating components (courtesy of Allis-Chalmers Mfg. Company).



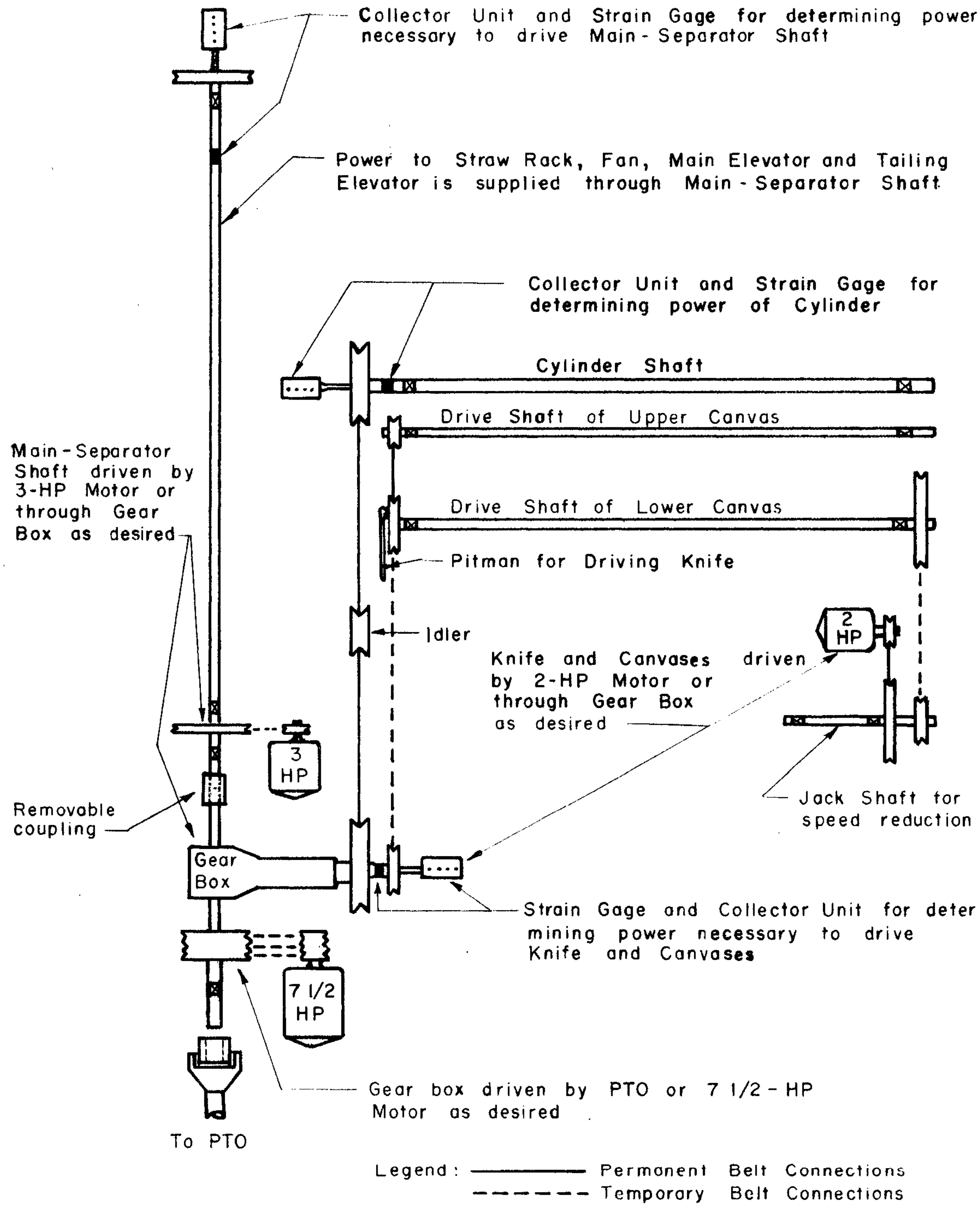


Fig. 8. Schematic representation of the drive combinations available on the combine.

attached directly to the gear box on one end and supported by a bearing on the other end. The pto was then keyed to the short shaft when being used.

For introducing power into the system with the 3-hp motor, the main-separator shaft was cut and a pulley mounted on the shaft. The shaft was supported by two bearings. A coupling was used when it was desired to drive the main-separator shaft through the gear box.

A pulley was mounted on the right end of the lower canvas drive shaft for connecting the 2-hp motor to the cutting and feeding mechanism. This permitted the knife (or pickup attachment) and canvas to be driven by the 2-hp motor or through the gear box by connecting the proper belts.

Electric motors and motor mounts

The selection of the motor size was made on the basis of preliminary studies made in the summer of 1955 and from a review of the literature. Preliminary studies indicated that the average power requirement for the knife and canvas drive was 1.5 hp and for the main-separator drive was 2.5 hp. Burrough (5) indicated that the average power requirements of the cylinder for a similar-sized combine was 6 hp at a feed rate of 70 lb per min and that the cylinder load was characterized by high peak overloads. A 2-hp motor was selected for the knife and canvas drive, a 3-hp motor for the main-separator drive and a 7.5-hp motor for the cylinder drive.

The mount of the 7.5-hp motor was bolted to the tongue assembly of the combine as shown in Figure 9. A slotted frame was used so that the belts could be tightened by means of draw bolts. This arrangement permitted the belts to be tightened without the use of an idler. Three Class B v-belts were used for connecting the motor to the load.

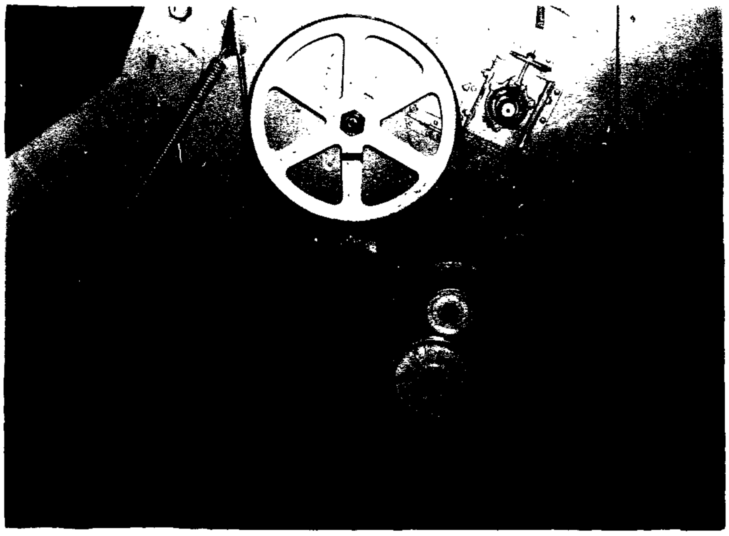
The 3-hp motor was mounted directly under the grain bin. Part of the pulley for this motor is visible in Figure 9 although the motor is not visible. A single Class B v-belt was used for connecting the motor to the load and the belt was tightened with an adjustable idler.

The 2-hp motor mount is shown in Figure 10. The motor was suspended directly beneath the cylinder on the side of the combine. A jack shaft was mounted on the frame for speed reduction. The jack shaft mounting was designed so that the belt connecting the motor to the jack shaft could be tightened by positioning the jack shaft. This belt remained in place at all times. The belt connecting the jack shaft to the drive shaft of the lower canvas was tightened by an idler. A single Class B v-belt was used on both connections.

Motor performance characteristics. Performance characteristics data were obtained for each of the motors used in the field study. These tests were made to check the

Fig. 9. Close-up view showing the mount and position of the 7.5-hp motor. Note the pulley beneath the grain bin for the 3-hp motor.

Fig. 10. Close-up view showing the mount and position of the 2-hp motor.



performance of the motors against the data supplied on similar motors by the General Electric Company. The data on the 7.5-hp and 2-hp motors were found to agree very closely with the data supplied by the manufacturer; however, some difference was found in the performance of the 3-hp motor. It was noted that the efficiency of the 3-hp motor was 3.5 to 4 points higher under most operating conditions of the motor than the manufacturer's data had indicated. All performance data were checked twice and the results agreed within experimental error.

The performance data of the motors were obtained by loading with a 15-hp electric dynamometer in the laboratory of the Electrical Engineering Department, Iowa State College. The motors were coupled directly to the dynamometer. A 208-volt, 60-cycle power supply was used in conducting the tests. The results of the tests are presented graphically in Figures 11, 12 and 13, and the data are tabulated in Tables III, V and VI in Appendix B.

Instrumentation

Electric-resistance strain gages

Electric-resistance strain gages were used to determine the torque of the main-separator shaft, the cylinder shaft and the knife (or pickup attachment) and canvas shaft. The

Fig. 11. Performance characteristics of the 7.5-hp motor.

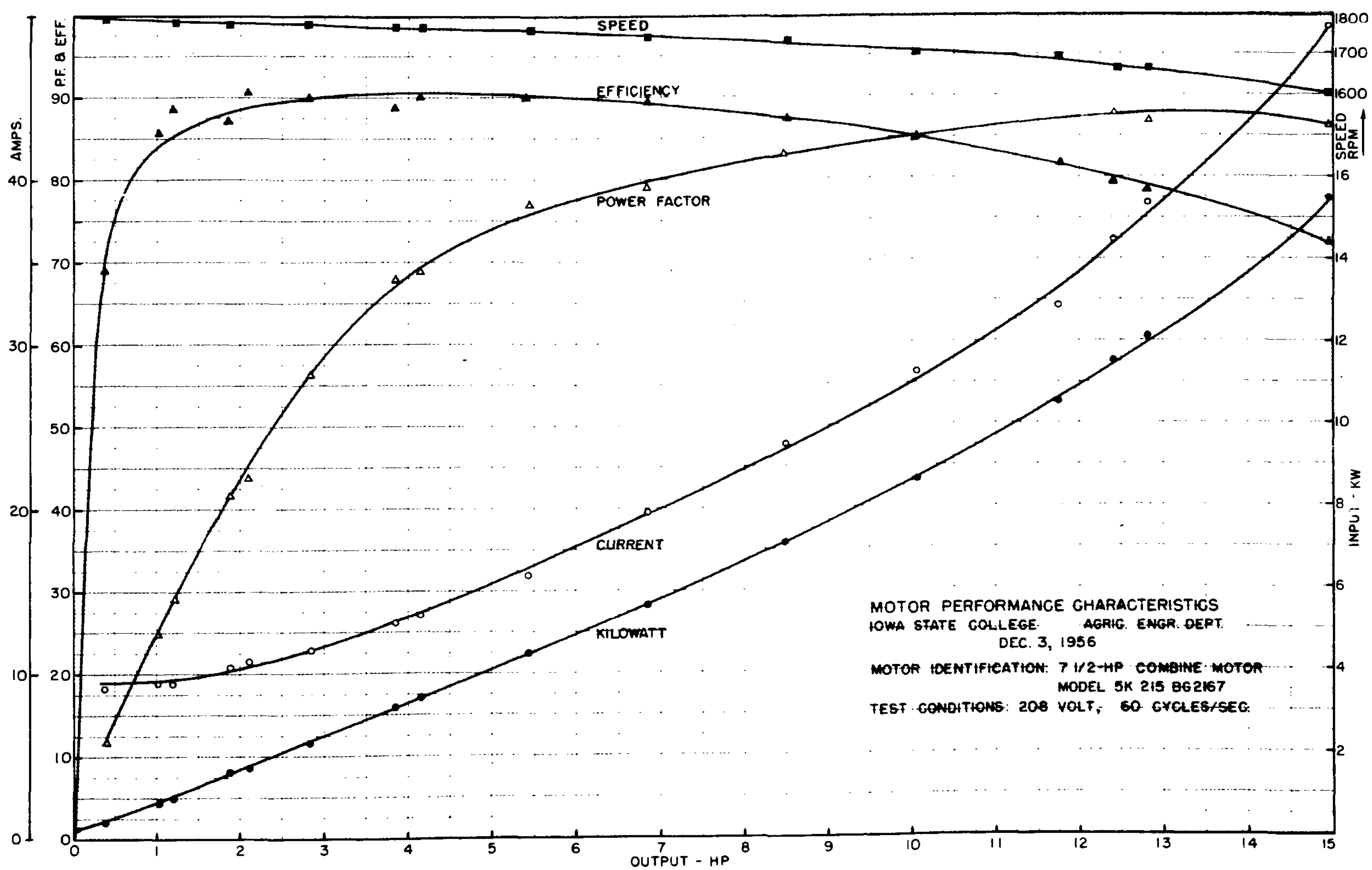

SPEED
EFFICIENCY
POWER FACTOR
CURRENT
KILOWATT
AMPS.
P.F. & EFF.
SPEED RPM
INPUT - KW
OUTPUT - HP
MOTOR PERFORMANCE CHARACTERISTICS
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
DEC. 3, 1956
MOTOR IDENTIFICATION: 7 1/2-HP COMBINE MOTOR
MODEL 5K 215 BG2167
TEST CONDITIONS: 208 VOLT, 60 CYCLES/SEC.

Fig. 12. Performance characteristics of the 3-hp motor.

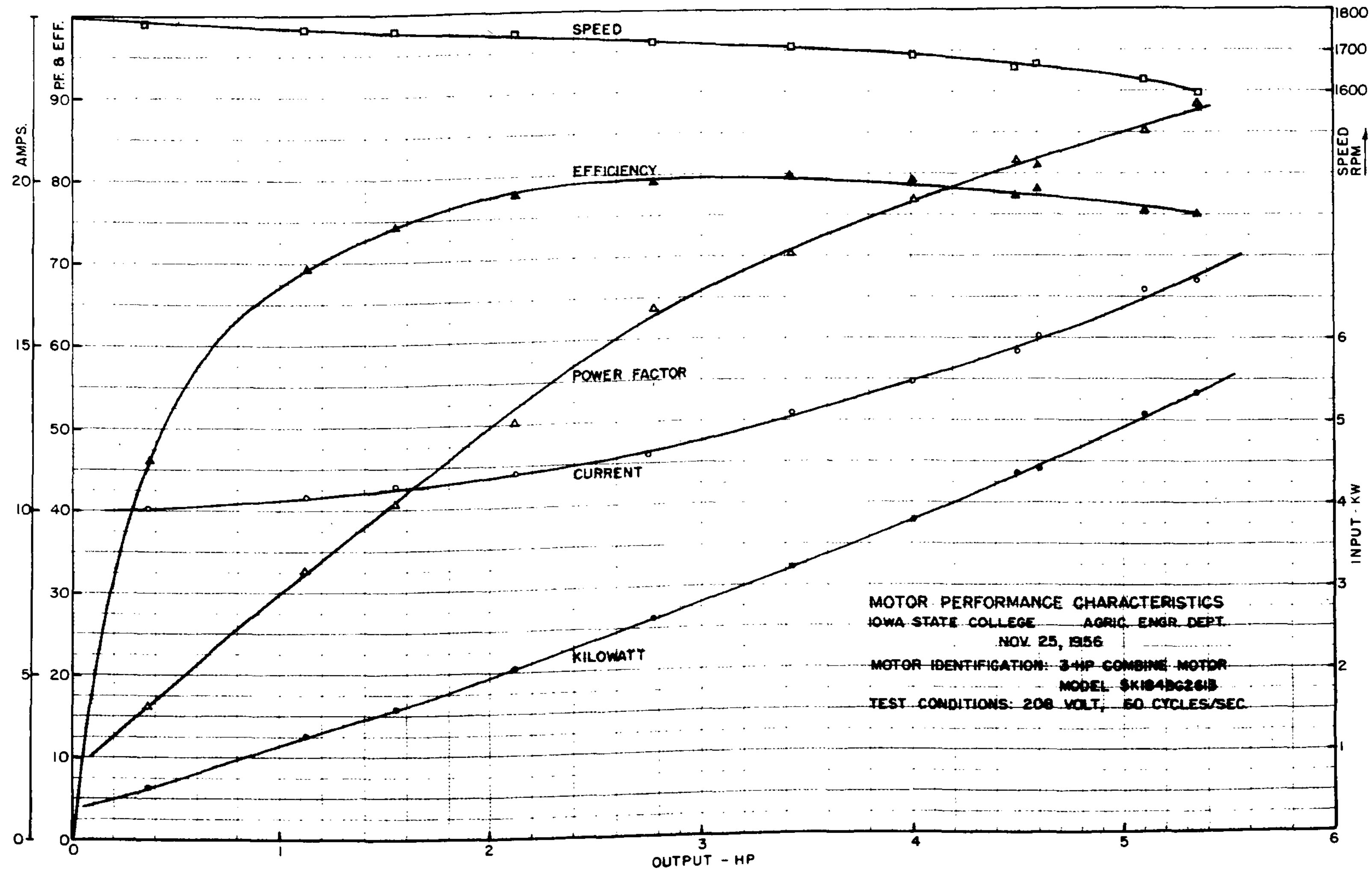
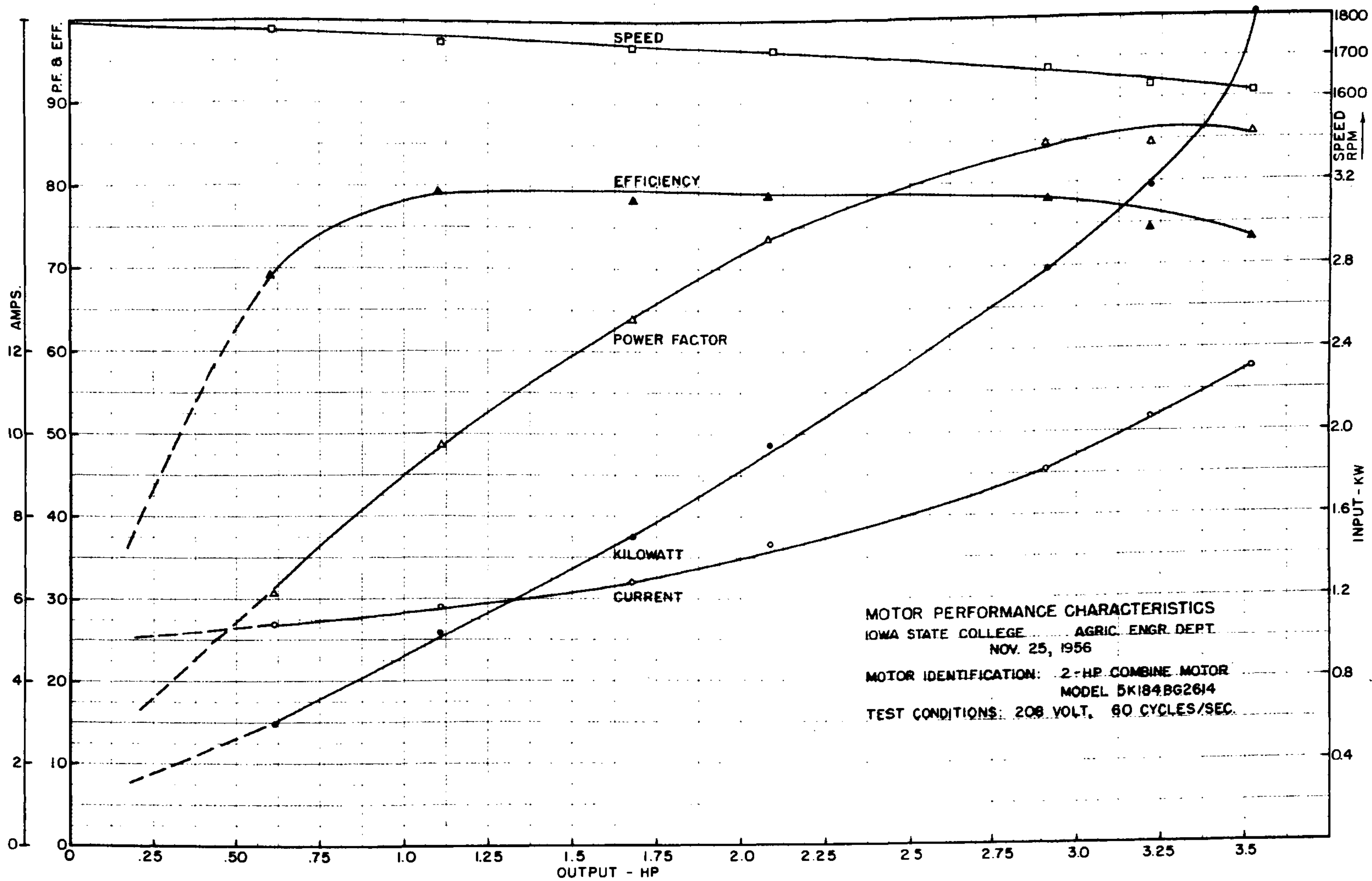

SPEED
EFFICIENCY
POWER FACTOR
CURRENT
KILOWATT
AMPS.
P.F. & EFF.
SPEED RPM
INPUT - KW
OUTPUT - HP
MOTOR PERFORMANCE CHARACTERISTICS
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
NOV. 25, 1956
MOTOR IDENTIFICATION: 3-HP COMBINE MOTOR
MODEL
TEST CONDITIONS: 208 VOLT, 60 CYCLES/SEC.

Fig. 13. Performance characteristics of the 2-hp motor.


SPEED
EFFICIENCY
POWER FACTOR
KILOWATT
CURRENT
MOTOR PERFORMANCE CHARACTERISTICS
IOWA STATE COLLEGE   AGRIC. ENGR. DEPT.
NOV. 25, 1956
MOTOR IDENTIFICATION: 2-HP COMBINE MOTOR
MODEL 5K184BG2614
TEST CONDITIONS: 208 VOLT, 60 CYCLES/SEC.
AMPS.
P.F. & EFF.
SPEED RPM
INPUT - KW
OUTPUT - HP
0
.25
.50
.75
1.0
1.25
1.5
1.75
2.0
2.25
2.5
2.75
3.0
3.25
3.5
1800
1700
1600
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
90
80
70
60
50
40
30
20
10
12
10
8
6
4
2

gages were mounted with Duco Cement and dried according to the recommendation of the manufacturer and according to the theory discussed by Dobie and Isaacs (7). The positions of these gages can be seen in Figure 8.

In order to mount the gages, several slight modifications were necessary. None of the modifications affected the performance of the combine. On the main-separator shaft, it was necessary to cut a keyway in the shaft so that the wires carrying the signal from the gages could be taken out to the collector unit. The wires were glued in the keyway with Duco Cement so that they would not interfere with the bearing.

On the cylinder shaft, the speed-adjusting mechanism was removed to make room for mounting the gage. The sheave width was adjusted with three bolts and it was necessary to make the cylinder speed changes with the cylinder stopped. This method worked satisfactorily since it was not necessary to change the cylinder speed very often.

In addition to the two above modifications, the cleats attaching the knife and canvas drive pulley to the shaft were removed to make room for mounting the gage. The pulley was then attached by a pin.

Since the main-separator shaft and the knife and canvas shaft were only 7/8 inch in diameter, a small gage was needed for these shafts. For this reason, SR-4 type C-7 electric-resistance strain gages were chosen. This gage has a gage resistance of 500 ohms and a gage factor of 3.18. The gages were trimmed so that they were approximately 3/8 inch long by 7/32 inch wide.

The cylinder shaft was 1-3/8 inches in diameter and did not pose any problem for mounting the gage. For the cylinder, SR-4 type C-5 electric-resistance strain gages were chosen. This gage has a gage resistance of 350 ohms and a gage factor of 3.32.

Mercury-bath collector unit

For conducting the signal from the rotating shaft, a mercury-bath collector unit was used. The collector unit was similar to the one designed by Burrough (6) and used by Bockhop (4). The shaft of the collector unit was connected to the rotating shaft by a piece of rubber tubing.

No trouble was found in the performance of the mercury-bath collector unit at speeds less than 1000 rpm. At speeds greater than 1000 rpm, trouble was encountered with mercury being moved from one cell to another. This often resulted in short or open circuits in the strain-gage circuit and necessitated frequent changing of the collector unit. This difficulty could probably be eliminated if the units were precision made so that the rotating disks would not have as great a tendency to sling the mercury at high speeds.

Some difficulty was encountered with a reaction between the mercury and solder used in attaching the wires to the disk. Reaction was also noted between the mercury and brass bolts used for attaching the wires to the unit. The reaction caused the mercury to form a black powder-like material and resulted in removing the solder and heads of the bolts. This difficulty was eliminated by not using solder and by using steel bolts instead of brass.

Strain-gage recording equipment

For recording the signal from the rotating shaft, a two-channel Model BL222 brush oscillograph with two Model BL320 amplifiers was used. Each channel of the oscillograph was equipped with an electric stylus and an event marker.

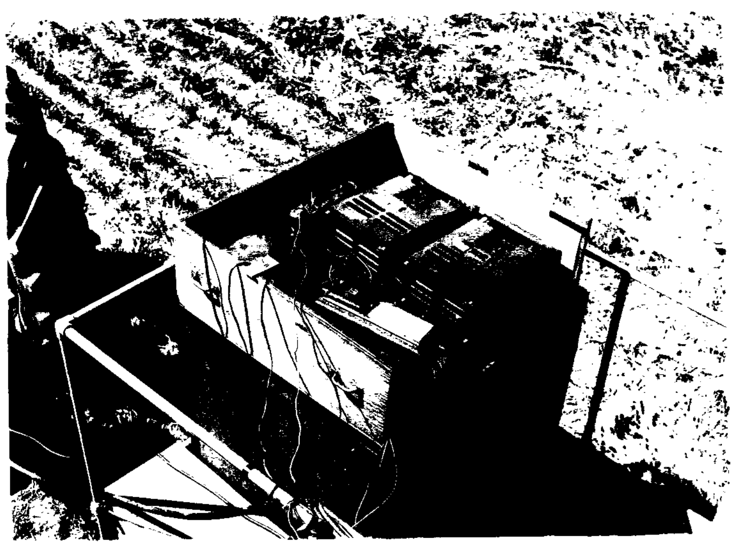
The instruments were carried in a special instrument trailer which bolted directly on to the side of the combine. The trailer was supported by three swivel wheels as shown in Figure 14. The instruments were mounted in the instrument trailer as shown in Figure 15. A 110-volt, 60-cycle, d-c generator was used as a power source for the instruments.

Wires from the collector units were connected directly to the amplifiers of the recording equipment. Color coding of the wiring was used to facilitate repairs that had to be made in the field and to make it easier to connect the gages properly to the amplifier when changing gages.

Revolutions of the shafts were recorded by electrically

Fig. 14. Overall view of instrument trailer bolted to the side of the combine.

Fig. 15. Close-up view showing strain-gage instruments mounted in the trailer.



activated event markers. A copper cam was mounted on the collector-unit shaft and used to activate a set of distributor breaker points. The circuit for recording the revolutions was energized by a 6-volt, dry-cell battery in series with the breaker points and the event-marker solenoid. With paper speed known, the revolutions per minute were calculated.

The oscillograph recorded the unbalance in a Wheatstone bridge that was calibrated in pound-feet of torque. Horsepower was calculated from the torque and speed measurements. Calibration of the shafts is explained in the procedure and a sample calculation of power is recorded in Appendix A.

Electrical recording equipment

Two General Electric strip-chart, three-phase recording wattmeters were used to record the power input to the motor. The instruments had chart speeds ranging from 1/4 in. per hr to 120 in. per min. The 60 and 120 in. per min speeds were used.

The wattmeters worked satisfactorily under most conditions. Some trouble was encountered with the ink splashing out of the inkwells under field conditions; however, this did not pose any great problem since the amount of ink was small and could be soaked up with a cloth or sponge. Some difficulty was encountered with the instrument's re-roll drive at the higher paper speed.

The charts for the wattmeters were driven by the 110-volt generator previously described. The paper drives for the strain-gage equipment and the wattmeters were energized by the same switch. The simultaneous switching synchronized the charts and permitted easier chart analysis.

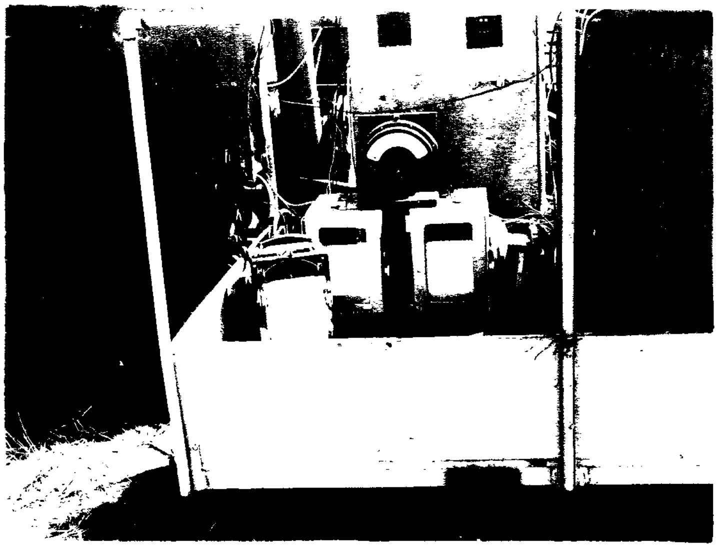
An Esterline-Angus recording voltmeter was used to record the generator voltage. The instrument was an ink-type recorder and the chart was driven by a spring. A paper speed of 0.2 of an inch per second was used in all the tests. This was the maximum paper speed of the instrument. A view of the electrical instruments is shown in Figure 16.

Control panel

In the design of the control panel, facilities had to be made for three wattmeter circuits. Two wattmeters were available for the test, so it was decided that one wattmeter should be used for measuring the power input to the 7.5-hp motor at all times and the other wattmeter should be used for measuring the power input to the 3-hp and 2-hp motors. With this in mind, the control circuit was designed as shown in Figure 17. Its operation is described below.

The power for the electrical coupling was brought in to the main switch. The main switch was used to de-energize the circuits to all motors in case of a short circuit. On the load side of the main switch, a circuit was established for

Fig. 16. Close-up view showing the position of the electrical instruments in the trailer.



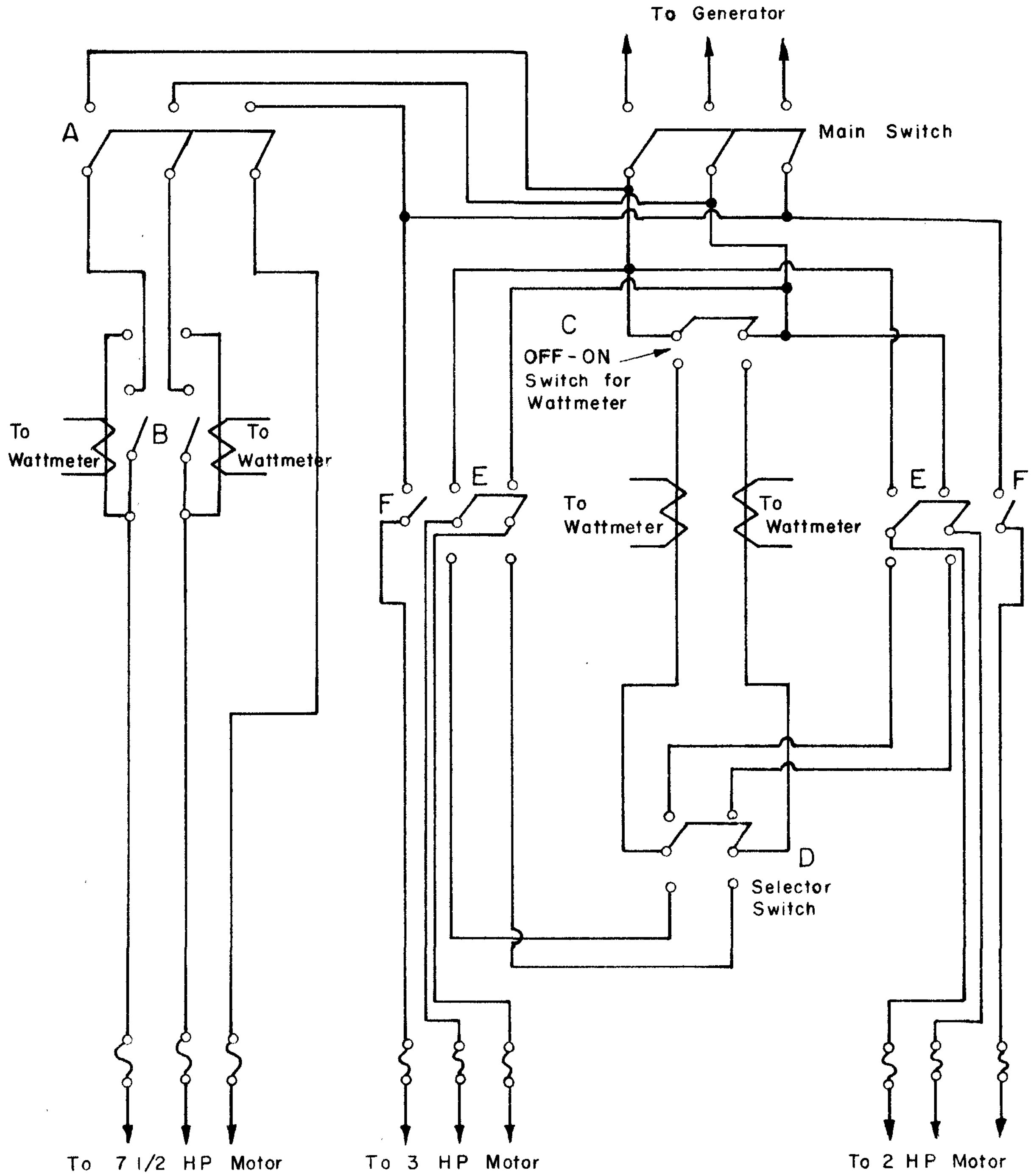


Fig. 17. Schematic representation of panel board.

each motor and provisions were made for inserting current transformers into the circuit for use with the wattmeters. An off-on switch (A)* and shunting switches (B) were put in the circuit for the 7.5-hp motor. This permitted the motor to be turned off or on as desired and permitted the current coils of the wattmeter to be shunted when the motor was starting. Protection was provided for the 7.5-hp motor by three 30-amp, time-delay fuses.

For the 2- and 3-hp motors, a common wattmeter circuit was used. This prevented simultaneous power measurements; however, it permitted switching the wattmeter from one motor to the other while the trailer was in motion simply by the operation of two switches. An off-on switch (C) was used for energizing the common circuit and a selector switch (D) used for selecting the motor. The off-on switch permitted the meter to be shunted when the motors were being started. Power could be measured for either motor by diverting the current through the wattmeter circuit and making the appropriate selection with the selector switch. Note that the double-pole, double-throw switch (E) in the individual motor circuit was used to complete the circuit through the wattmeters. The single-pole, single-throw switch (F) in the individual motor circuit was used for breaking the third line when it was

---

*Letters refer to Figure 17.

desired to cut the motor off without the use of the main switch. The 3-hp motor was fused with 16-amp, time-delay fuses and the 2-hp motor was fused with 12-amp, time-delay fuses.

The panel board worked very satisfactorily in the field and no trouble was encountered. The safety features that were incorporated in the design of the panel were worth the time that was necessary to build it. The panel board afforded meter protection against current surges, reduced the possibility of short circuits, and eliminated the possibility of someone's getting shocked. The back of the panel board was covered with a piece of masonite supported by brackets. When it was desired to make any checks in the circuits, the covering was lifted off and the necessary checks made.

Procedure

Calibration of strain-gage equipment

After the strain-gages had been bonded to the shaft, each shaft was calibrated and the gages waxed to prevent moisture from disturbing the bond. After use, the gages were calibrated again to check their condition after use. In checking the cylinder calibration, it was discovered that the wrong calibration resistor had been used in the original calibration. The original calibration data for the cylinder shaft were reproduced by using the same calibration resistor. This verified that all the cylinder gages had functioned properly during the study. The correct cylinder calibration was then obtained by using the proper calibration resistor. The main-separator and the canvas and knife calibration data were reproduced and verified the original data.

For calibrating the shafts, a 3-ft torque arm was used. All calibrations were made under static conditions with the exception of one. A dynamic calibration of the main-separator shaft was made to see if any difference existed between the static and dynamic calibrations. The torque for the dynamic calibration was applied and measured by means of a rope brake. The results of all the calibrations are shown in Figures 18, 19 and 20, and the data are tabulated in Table II of Appendix A. The calibrations before the tests and after the tests check very closely. The results of the static and dynamic calibrations of the main-separator shaft check very closely.

<u>Tests conducted</u>

Six different tests were conducted on the electrical couplings and the combine performance. Each of these tests was designed for a specific purpose and each is discussed below.

<u>Stationary load study</u>. Because of the varying conditions in the field, a stationary loading study was set up whereby the combine could be fed by means of a conveyor belt as shown

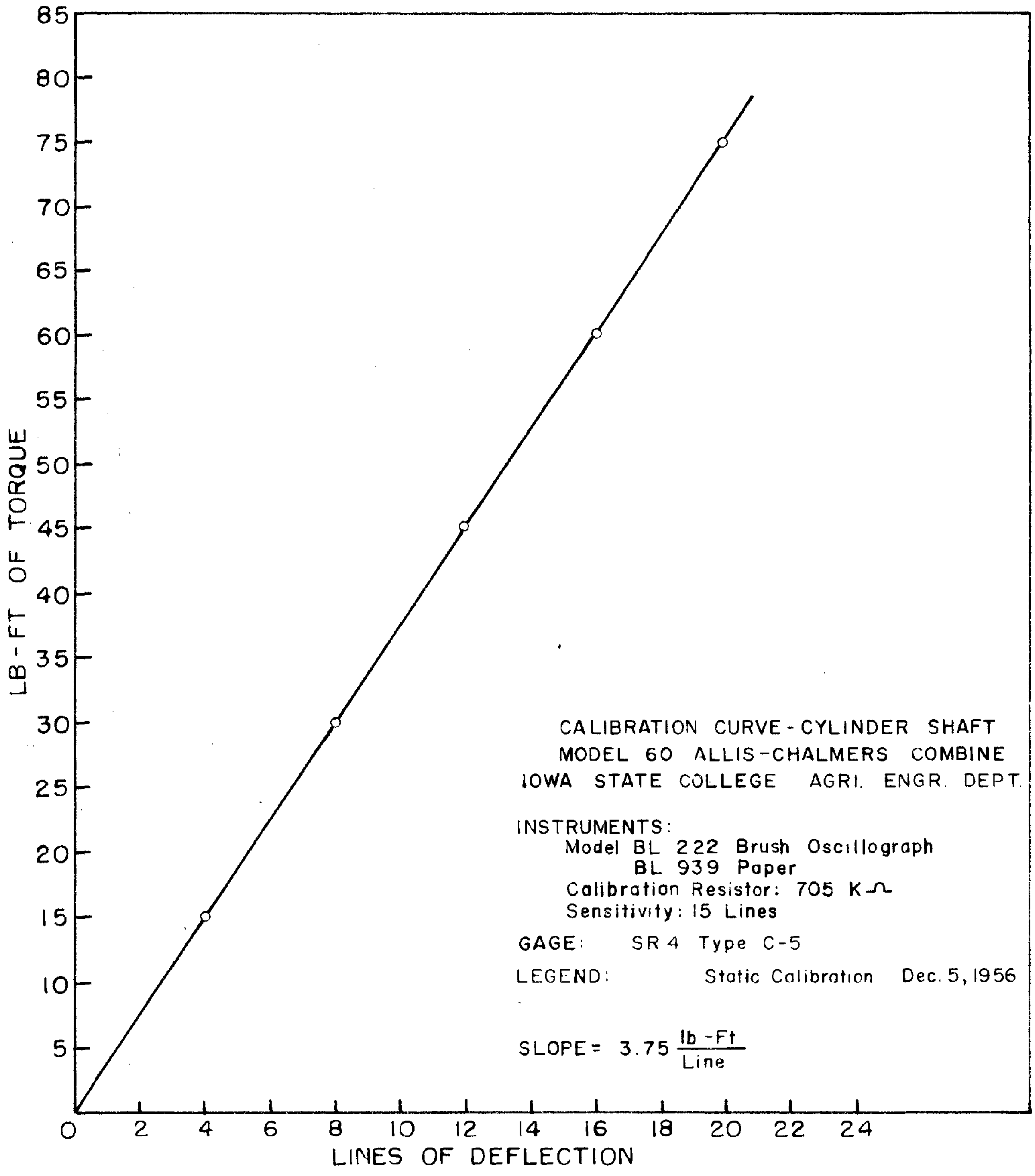


Fig. 18. Calibration curve of the cylinder shaft.

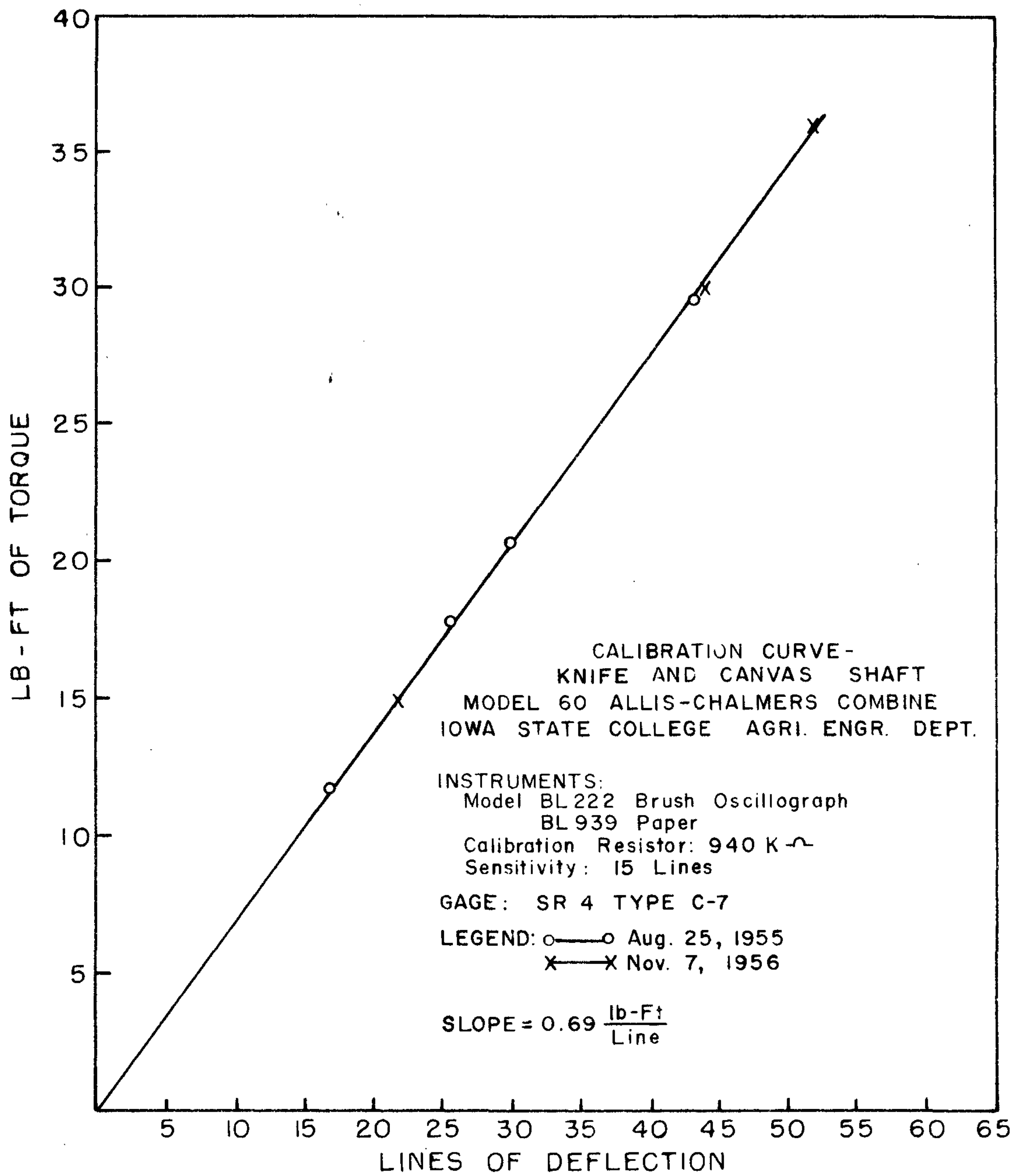


Fig. 19. Calibration curve of the knife and canvas shaft.

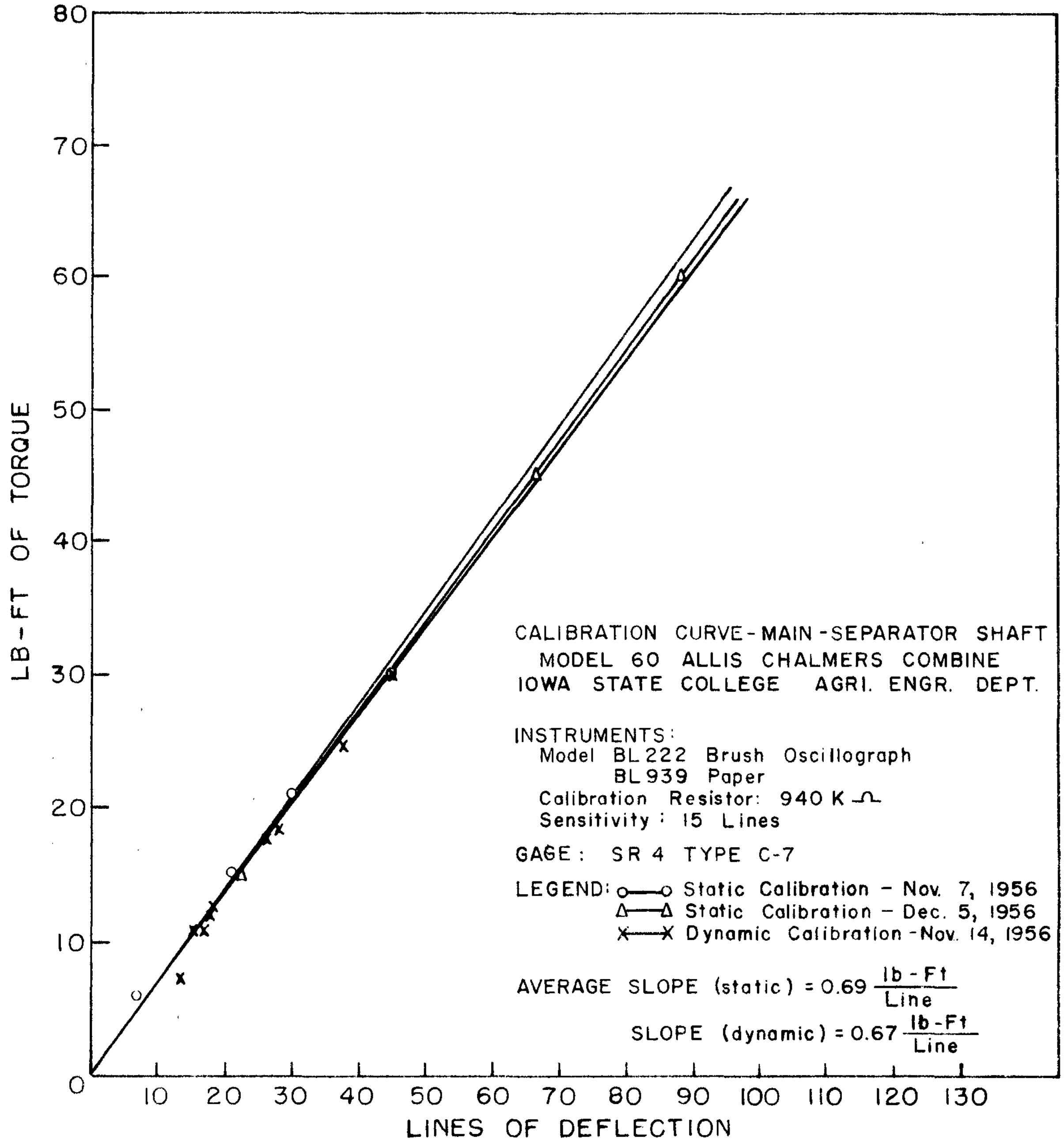


Fig. 20. Calibration curve of the main-separator shaft.

in Figure 21. The purpose of the test was to obtain data on the performance of the single-motor coupling, the multiple-motor couplings and the pto coupling at various load levels.

The conveyor was 20 feet long and was driven by a chain drive which in turn was driven from the pto of a tractor. The speed of the tractor was adjusted so that the conveyor belt speed was 1 fps (foot per second). The tachometer reading of the tractor was noted and the same conveyor belt speed was used throughout the study. Several checks were made on the conveyor belt speed to make sure that the speed remained the same. Since the conveyor belt speed was always 1 fps, a total of 20 seconds was required for the conveyor belt to clear itself.

Four loading levels were selected for the study. These were: 75 lb per min, 100 lb per min, 125 lb per min, and 150 lb per min. Since the conveyor always required 20 seconds to clear itself, the feed rate was determined by the amount of material placed on the conveyor belt. Unthreshed wheat straw was used for the tests; therefore, the above weights included the weight of straw and grain. The condition of the straw was dry and brittle.

Measurements were made on generator voltage, power input to the motors, and the speed and torque of the cylinder, main-separator and canvas shafts. The tractor throttle was set so that the generator would deliver rated voltage and frequency,

Fig. 21. Conveyor belt used for feeding the combine in the stationary load study.

and the same throttle setting was used throughout the test.

The straw was weighed for each run and spread as evenly as possible throughout the length of the conveyor belt. Since the straw was not spread over the entire width of the cylinder, the cylinder loads obtained with a particular feed rate with the conveyor belt feed is somewhat higher than the cylinder load obtained for the same feed rate when combining from a windrow in the field. This is discussed later in the discussion of the results of field studies in windrowed wheat.

Slug study. A study was conducted to evaluate the performance of the electrical couplings and the pto under conditions of momentary overloads. This study was made in the field with windrowed oats. Particular attention was given to analyses of the cylinder speed during overload periods and the recovery time necessary for the cylinder to again reach its normal speed.

To clarify terminology, the following definitions are given:

Slug: A mass of straw which causes an overload condition at the cylinder.

Cylinder slugging: A condition in which the cylinder has received a slug but has not stopped.

Cylinder jamming: A condition in which the cylinder is stopped due to an overload condition. This may be caused by a sustained overload or it may be caused by a very high momentary overload.

Overloaded cylinder: A cylinder which receives a load of such intensity that the speed drops 5 per cent or more.

Slug density: A number indicating the number of windrows making up a slug.

Slug length: The length of the slug in feet.

With the above terminology in mind, the slug study may be described as follows. Slugs were created by superimposing additional windrows on the original windrow. The superimposed material was obtained from adjacent windrows and was placed on the original windrow by hand. Care was taken to place all material in the same manner as the original windrow so that the material would feed into the cylinder properly. All slug lengths were 10 ft, and the slugs were placed far enough apart to allow the coupling being tested to restore the machine to equilibrium before another slug entered.

The tractor throttle was set to give rated voltage and frequency. This resulted in a forward speed of 3 fps. Checks made on the windrow density of a single windrow indicated that the feed rate was 50 lb per min when combining a single windrow. This was a very light load and the performance of all the couplings tested was satisfactory.

Slug densities of 2, 3, 4, 5, 6 and 8 were used in the study; however, only the results of the last two are discussed in this report. With a slug density of 6, the combine was driven by the pto coupling, single-motor coupling, and multiple-motor coupling (10.5 hp). The grain was very dry in this study. With a slug density of 8, the combine was driven by the pto coupling, multiple-motor coupling (10.5 hp) and multiple-motor coupling (12.5 hp). Measurements were made of generator voltage, power input to the motors and speed and torque of the cylinder and the main-separator shafts. In this study, the grain was damp and tough.

The slug study was designed so that the slug duration would be approximately equal to slug durations encountered under field conditions. With the tractor speed of 3 fps, the slug entered the cylinder in 3.3 seconds; however, considerably more time was necessary for the slug to clear the cylinder. The throttle setting was left unchanged as the slug was approached because it is almost impossible for the tractor operator to recognize a slug in advance and make appropriate changes in the throttle under normal field conditions.

Load-analysis and performance study in windrowed wheat. The two studies listed above were conducted under controlled conditions. Field studies were conducted to get an insight into the nature and magnitude of the loads under field conditions. The yield of the wheat was approximately 40 bushels per acre and the stand was thick. An 8-foot swath was windrowed to get a good load on the cylinder. At a forward speed of 3 fps, this gave a feed rate of 130 lb per min. Before cutting, the wheat was about 3 to 4 ft tall.

The amount of wheat available for the study was limited so it was necessary to design the study so as to make the greatest possible use of the wheat available. The field was cut up in 110-ft lengths. The 110-ft length windrow represented 1/50 of an acre and allowed ample time for the machine to come up to equilibrium. This gave enough for two replications for each drive combination. The strain-gage instruments were not working properly in part of the test and part of the charts were of no value. As a result, only one good record on each coupling was available for analysis.

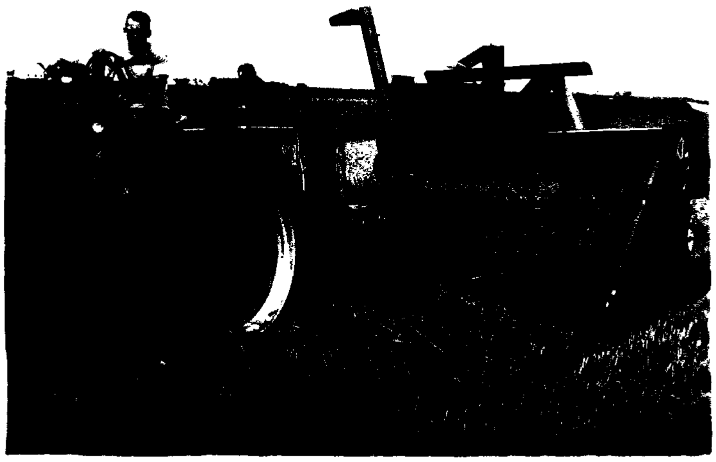
In conducting these studies, the combine was lined up with the windrow to be harvested and the complete length of the windrow was harvested before the machine stopped. With some of the electrical couplings, the cylinder jammed before reaching the end of the plot and it was necessary to stop and clear the cylinder. The instruments were turned on at the beginning of the run, and a complete record of the entire run was made. The forward speed of the tractor was 3 fps and the duration of each run was approximately 40 sec.

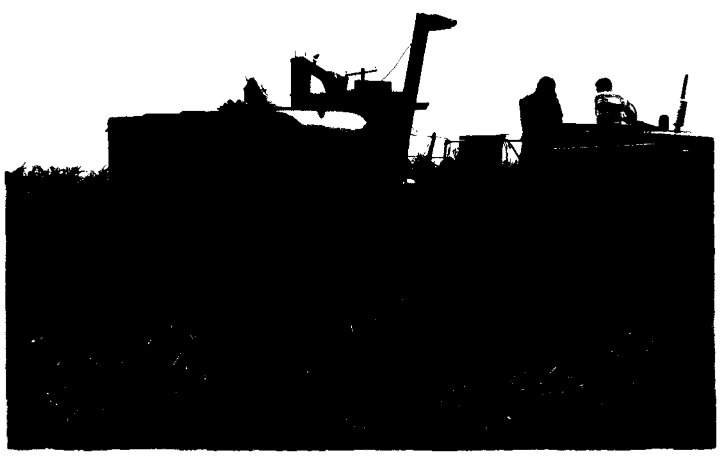
Tests were made of the single-motor coupling, the multiple-motor coupling (10.5 hp), the multiple-motor coupling (12.5 hp) and the pto. Measurements were made on generator voltage, wattage input to motors, speed and torque for the three load centers. Pictures of the field conditions are shown in Figures 22 and 23.

Load-analysis and performance study in soybeans. In addition to the load-analysis and performance study on windrowed

Fig. 22. Front view of combine showing windrow attachment picking up the windrow.

Fig. 23. Rear view of combine showing the straw coming out of the machine.





wheat, a load-analysis and performance study was conducted on soybeans. The purpose of this study was the same as the previous study, that is, to gain an insight into the nature and magnitude of the loads under field conditions.

The study was conducted in a heavy growth of soybeans. The beans were fully mature but not overly dry. Morning glory vines were present and tangled with the bean vines. Figures 24 and 25 show the condition of the crop and field when the study was conducted.

The single-motor coupling, the multiple-motor (10.5 and 12.5 hp) couplings, and the pto coupling were tested. It was necessary to operate the tractor at maximum throttle in order for the electric motors to maintain their speed. For this reason, the pto coupling was also tested at maximum throttle.

This study was conducted somewhat differently from the previous study in that no attempt was made to lay out plots. The machine was run down the row as shown in Figure 25, and the instruments were turned on for a period of 5 to 10 seconds as the machine moved through the field. Ten of these intervals were recorded for each coupling and the data were taken from these intervals. Data were recorded on some light crop conditions; however, the load was so light that the machine was running practically empty. The results of the light load study are not reported. Measurements were made on power input to the 7.5-hp motor and the torque and speed for

Fig. 24. Overall view showing the test being conducted in soybeans.

Fig. 25. Close-up showing the condition of the crop as it entered the cylinder.

the component parts of the combine.

Laboratory study of power loss in the cylinder drive. A laboratory study was conducted to determine the drive efficiency of the cylinder drive. Attempts were made to obtain the desired information from an analysis of the field studies and stationary load study; however, it was decided that conditions were too variable to get reliable results.

An a-c generator was mounted on the combine and connected to the cylinder as shown in Figure 26. For loading the generator, a resistance load rack was used as shown. This permitted loading the cylinder at the strain gage up to 12 hp.

Power was supplied to the motor by a 220-volt, 60-cycle infinite bus.

Power at the motor shaft was obtained by measuring motor input and using the kw input versus hp output curve for the motor. (See Figure 42, Appendix B). Power at the cylinder was determined from the speed and torque data taken with the strain-gage equipment. The formula used for calculating the drive efficiency was:

$$\text{Drive Eff.} = \frac{\text{Hp at cylinder}}{\text{Hp at motor shaft}} \times 100$$

Laboratory study of the electrical coupling performance. The data taken on the stationary load study and the field studies were not sufficient to determine fully what was happening to the electrical couplings under sustained overloads.

Fig. 26. Generator used for loading the cylinder
in the laboratory.

For example, no apparent difference was noted in the performance of the single-motor coupling and the multiple-motor coupling (12.5 hp) under sustained overloads. Inspection of the data indicated that the generator was overloaded; however, the evidence was not sufficient to justify any definite conclusions.

A laboratory experiment was set up whereby the electrical coupling could be loaded under conditions somewhat analogous to field conditions. The 7.5-hp motor was connected to an electric dynamometer so that it could be loaded as desired. To represent the other motors, a pure resistive load was used as shown in Figure 27.

Tests were conducted with a resistive load of 10 ohms per phase and with 22.5 ohms per phase. Since the voltage of the generator dropped as the load was increased, the resistive load also decreased. The resistive load of 10 ohms per phase was 3000 watts when the generator voltage was 173 volts (line to line) and the 22.5 ohms per phase resistive load was 1280 watts when the generator voltage was 170 volts.

The study was conducted with the same throttle setting as used in the stationary load study. The generator voltage and frequency, motor input and speed, and dynamometer hp were obtained from the tests.

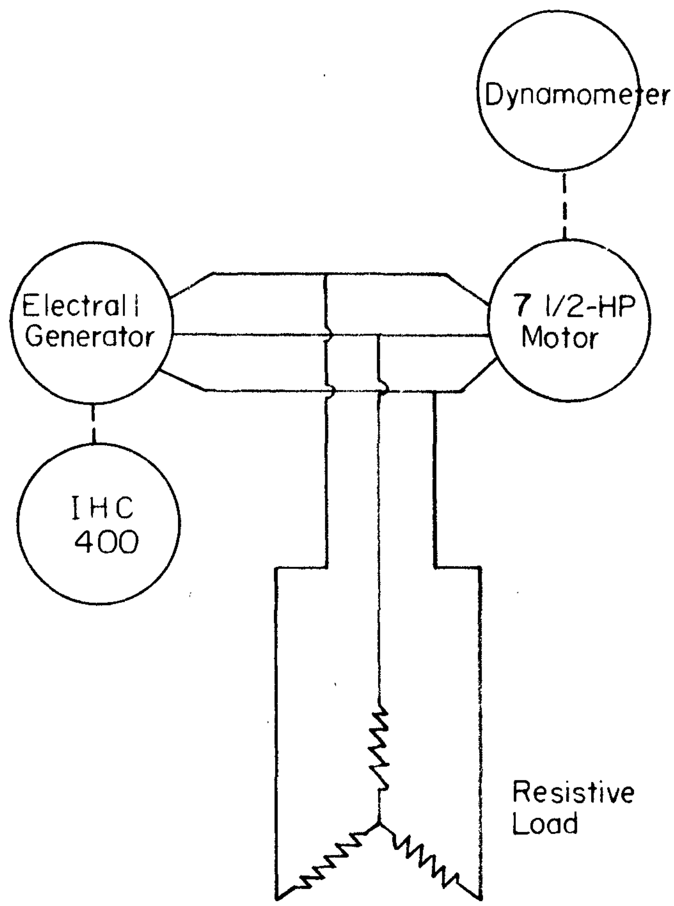


Fig. 27. Laboratory set-up for loading the electrical coupling.

Methods used in chart analysis

Two methods were used in the analysis of the strain-gage charts. These were: stratified sampling of the charts for obtaining average load data and continuous analysis of the charts for studying the nature and magnitude of the loads. Each of these are discussed below.

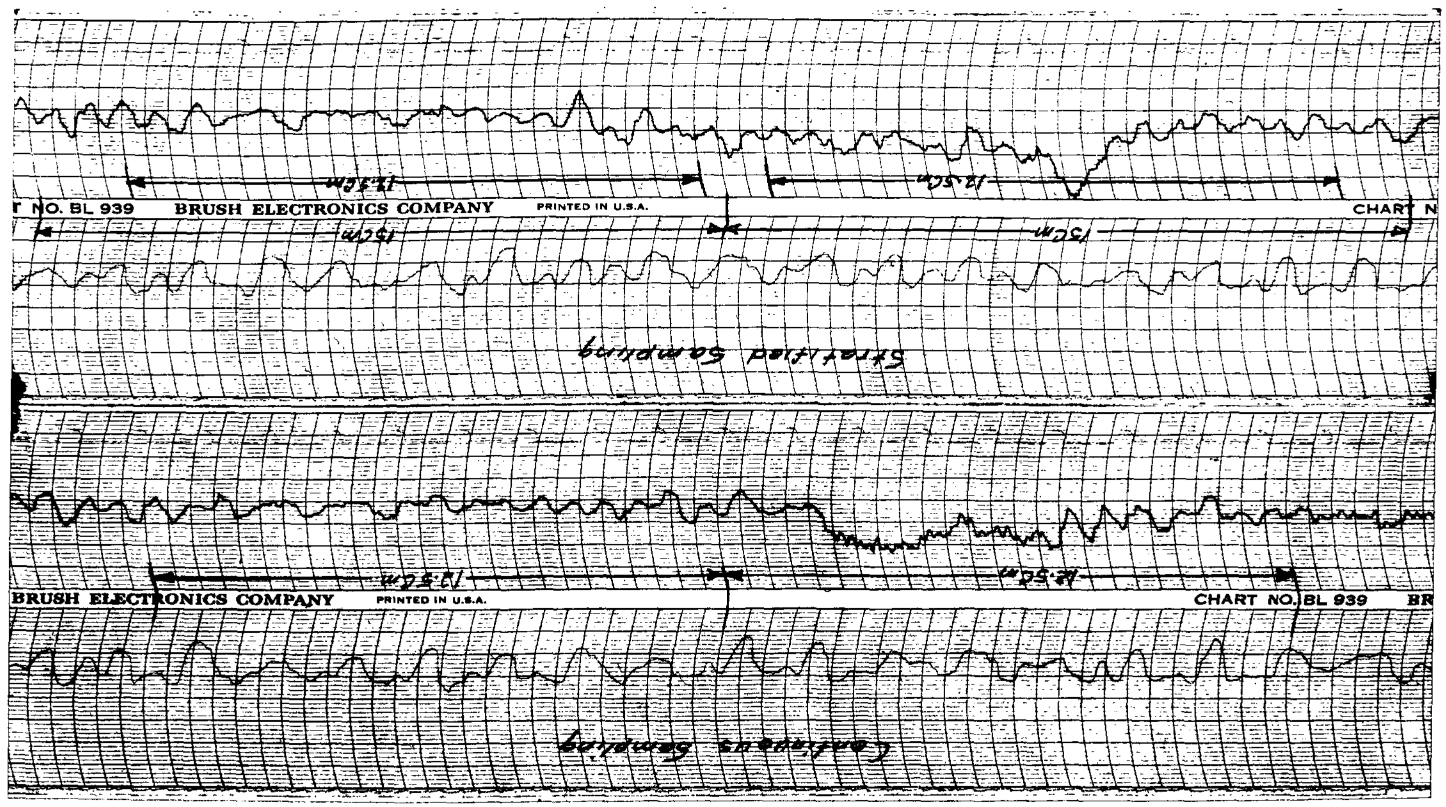
In the stratified sampling, ten readings were taken for each chart, and the average of the ten readings was used to represent the average load of the particular unit being measured. The charts were laid off in 15 cm sections and 12.5 cm were sampled within each section as shown in Figure 28. The 12.5 cm length of chart represented a time interval of 1 sec since the chart speed was 12.5 cm per sec. Since the chart was manufactured with lines 0.5 cm apart, this gave six possible starting points for the 12.5 cm length.

In the continuous sampling, the charts were divided into 12.5 cm lengths as shown in Figure 28. The entire 12.5 cm was analyzed. This gave an average reading over a 1 second period.

In determining the average torque during the 1 second interval, the area under the trace was planimetered and the average torque determined directly from the area. This is explained in Appendix A.

In determining the average generator voltage and power input to the motors, the average ordinate was determined by

Fig. 28. Methods of sampling strain-gage charts.


12.5cm
12.5cm
CHART NO. BL 939
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
15cm
15cm
Stratified Sampling
12.5cm
12.5cm
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
CHART NO. BL 939
Continuous Sampling

estimation by eye. Checks were made on several estimated readings by planimetering and the readings were found to agree very closely.

RESULTS AND DISCUSSION

Stationary Load Study

The purpose of the stationary load study was to determine the nature and magnitude of the power requirements of the combine at different load levels and to gain an insight into the performance of the electrical couplings at different load levels. The pto coupling was used to determine the nature and magnitude of the loads and the results of the pto runs were used as a guide or standard in the analysis of the electrical couplings. In the stationary load study, the no-load cylinder speed for the various couplings was between 1500 and 1550 rpm. The results of the study are summarized in Table I. Each reading presented in Table I is the average of 10 readings recorded in Tables IX through XIII in Appendix C.

The average data presented in Table I for the pto coupling represent the average power demands of the cylinder and main-separator shaft. The average data for the main-separator shaft indicate that the power demands of cleaning and separating units are not affected by the load level. The average data for the cylinder drive indicate that the power demands of the cylinder are influenced greatly by the load level of the machine. Further inspection of the data recorded in Table I for the electrical couplings shows that the elec-

Table I. Summarized results of stationary load study[1/]

Coupling	Feed rate	Cylinder shaft			Main-separator shaft			Voltage
	Lb/min	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp	
Pto	75.00	19.92	1515	5.74	16.03	535	1.63	
	100.00	23.53	1522	6.80	16.03	542	1.65	
	125.00	34.32	1503	9.82	14.79	535	1.51	
	150.00	36.30	1490	10.29	No data			
Single-motor	75.00	17.53	1471	4.91	12.68	525	1.27	208
	100.00	16.86	1465	4.70	No data			209
	125.00	25.68	1435	7.02	13.31	509	1.29	206
	150.00	28.55	1322	7.18	12.01	471	1.08	195
Multiple-motor (10.5 hp)	75.00	19.44	1499	5.55	16.44	575	1.80	211
	100.00	22.70	1430	6.18	14.75	564	1.58	203
	125.00	27.68	1330	7.01	15.07	551	1.58	192
	150.00	27.33	1301	6.76	13.38	548	1.40	187
		25.12	1383	6.61	15.59	560	1.66	198
Multiple-motor (12.5 hp)	75.00	19.44	1464	5.36	No data			201
	100.00	25.64	1433	6.99	16.82	562	1.80	198
	125.00	26.10	1399	6.95	16.97	558	1.80	195
	150.00	33.58	1142	7.30	17.10	532	1.73	172

[1/] The no-load cylinder speed for the various electrical drives was approximately 1500 rpm, while the no-load speed for the pto drive was approximately 1520.

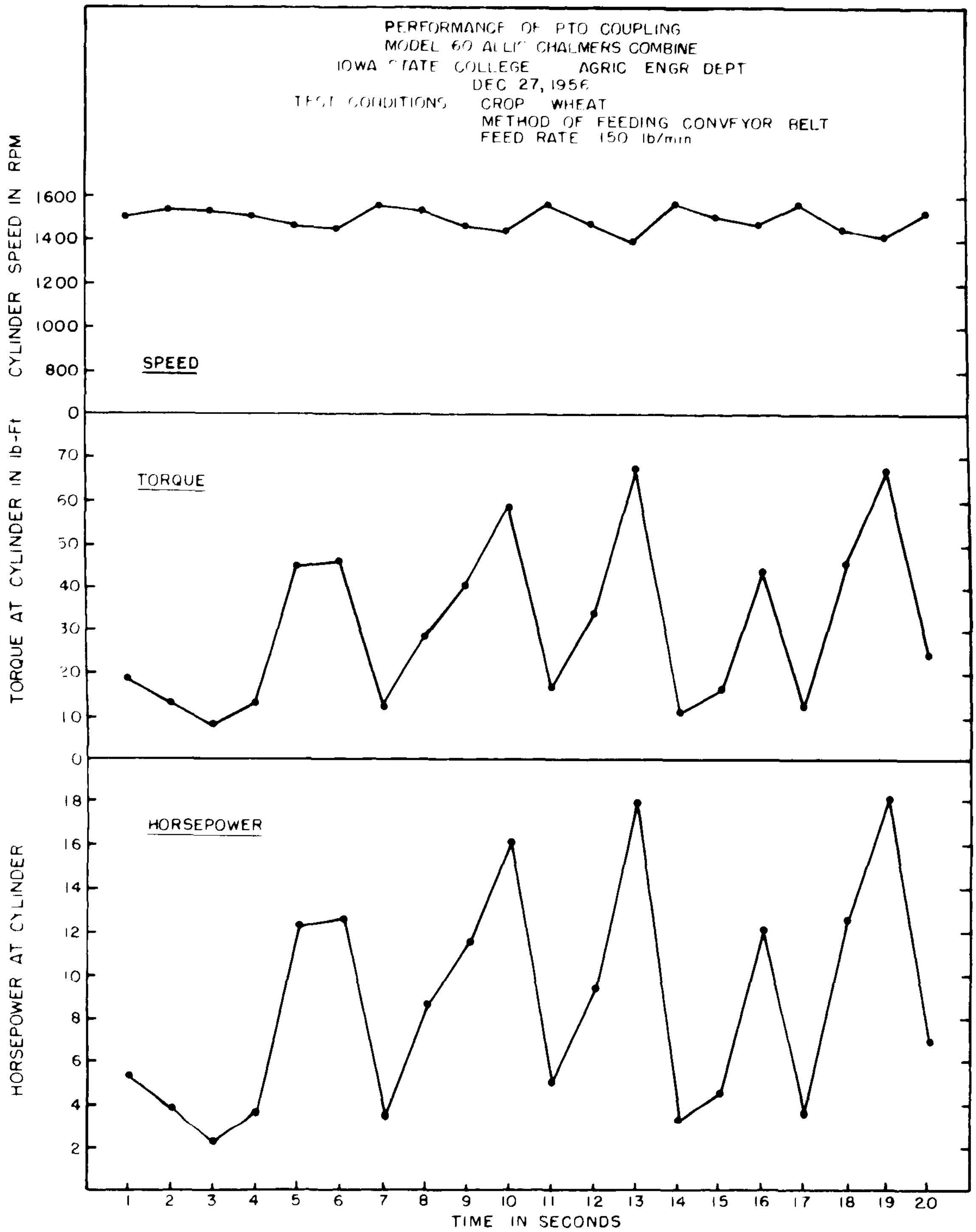
trical couplings did not deliver the required power to the cylinder under the heavier load conditions. In order to determine the nature and magnitude of the loads and to study the performance of the electrical coupling, a time analysis of the charts for the 150 lb per min feed rate was made.

<u>Load-analysis and performance of the pto at the 150 lb per min feed rate</u>

A time analysis of the data collected on the pto coupling at the 150 lb per min feed rate is presented in Figure 29. The chart was arbitrarily started at a time of 1 second which was about the time the material started entering the cylinder. An inspection of Figure 29 reveals that the power demands of the cylinder are characterized by high momentary overloads. The torque plot in Figure 29 indicates that the load pattern of the cylinder is very irregular. For example, the torque at the 3 second point is only 7.8 lb-ft; however, at the 5 and 6 second points, the torque is approximately 45 lb-ft. This same general relationship is noted throughout the trace.

The performance of the pto coupling was satisfactory although the cylinder load was characterized by high peak overloads. The plot of the speed in Figure 29 reveals that the pto coupling maintained the cylinder speed at a high level during the entire run. Although the speed dropped to slightly less than 1400 rpm at the 13-second point, the speed recovery was very rapid. The pto coupling is a rigid connection

Fig. 29. Speed, torque and horsepower at the cylinder versus time for a feed rate of 150 lb per min with pto coupling.


PERFORMANCE OF PTO COUPLING
MODEL 60 ALLIS CHALMERS COMBINE
IOWA STATE COLLEGE AGRIC ENGR DEPT
DEC 27, 1956
TEST CONDITIONS CROP WHEAT
METHOD OF FEEDING CONVEYOR BELT
FEED RATE 150 lb/min
CYLINDER SPEED IN RPM
SPEED
TORQUE AT CYLINDER IN lb-Ft
TORQUE
HORSEPOWER AT CYLINDER
HORSEPOWER
TIME IN SECONDS

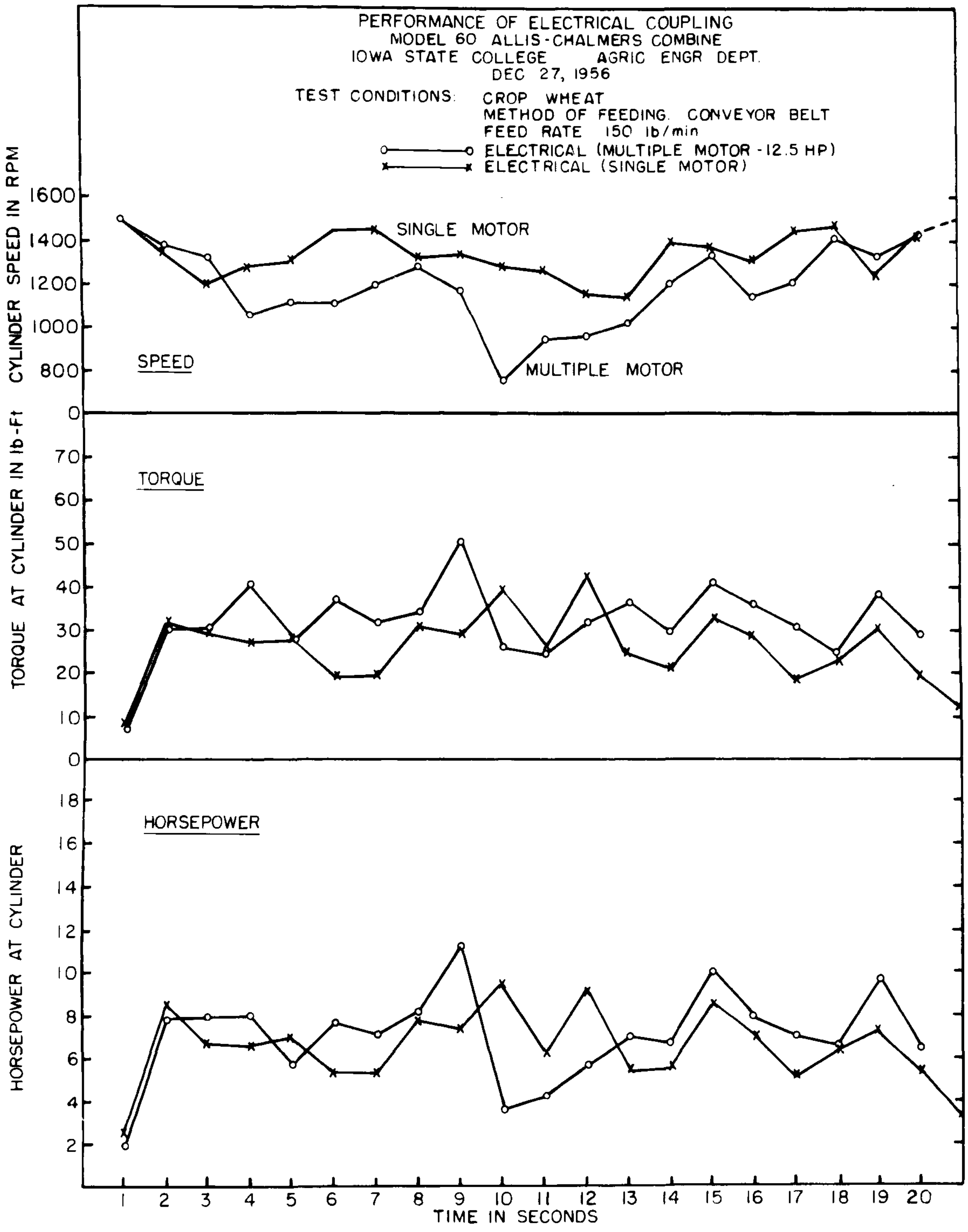
between the engine drive shaft and the load; therefore, the tractor responds to any increase in load instantaneously. The governor response is immediate during a load increase, and the tractor begins to restore the coupling to a state of equilibrium immediately.

The ability of the pto coupling to maintain the cylinder speed allows the cylinder to pulverize the mass of straw very quickly. This results in keeping the threshing ability of the cylinder at a high level during the peak overload period.

Performance of the single-motor and multiple-motor coupling (12.5 hp) at 150 lb per min feed rate

A time analysis of the data collected on the electrical couplings is presented in Figure 30. The difference in the performance of the single-motor and the multiple-motor couplings can be explained by the sequence of events during the first 5 seconds of the run. An examination of Figure 30 reveals that at the 1-, 2-, and 3-second points of the run very little difference exists between the torque plots for the two couplings; however, the cylinder speed of the multiple-motor coupling is considerably higher at the 3-second point than the cylinder speed for the single-motor coupling and consequently the cylinder power for the multiple-motor coupling at the 3-second point is greater than the cylinder power for the single-motor coupling. This indicates that with the same load pattern, the single-motor coupling is forced to

Fig. 30. Comparison of the single-motor and the multiple-motor coupling at a feed rate of 150 lb per min.


PERFORMANCE OF ELECTRICAL COUPLING
MODEL 60 ALLIS-CHALMERS COMBINE
IOWA STATE COLLEGE AGRIC ENGR DEPT.
DEC 27, 1956
TEST CONDITIONS: CROP WHEAT
METHOD OF FEEDING: CONVEYOR BELT
FEED RATE 150 lb/min
ELECTRICAL (MULTIPLE MOTOR - 12.5 HP)
ELECTRICAL (SINGLE MOTOR)
CYLINDER SPEED IN RPM
SPEED
SINGLE MOTOR
MULTIPLE MOTOR
TORQUE AT CYLINDER IN lb-ft
TORQUE
HORSEPOWER AT CYLINDER
HORSEPOWER
TIME IN SECONDS

absorb more energy from the fly wheel action of its drives than the multiple-motor coupling. The same general relationships are found to exist between the 18- and 19-second points.

Before making any definite conclusions concerning the performance of the two drives, a study of the region between the 3-second point and the 18-second point should be made. No attempt will be made to compare the drives in this region, but an attempt will be made to point out some conditions which are important in the analysis of electrical couplings. First, a discussion of the multiple-motor coupling will be made.

The inability of the electrical coupling to maintain the speed at the cylinder is very evident when one inspects the cylinder speed versus time curves for the multiple-motor coupling in Figure 30. This can be seen by an inspection of the 2-, 3- and 4-second points. Between points 2 and 3 and 3 and 4, the torque increases; however, the speed decreases enough to offset the torque increases and this results in practically no change in power at the cylinder. At the 4-second point, the speed drops to such an extent that the electrical coupling is no longer an efficient means of power transmission. Inspection of the wattmeter and voltage data (Table XIII, Appendix C) reveals that the motor input averages over 14000 watts and the generator voltage averages about 170 volts for the remainder of the run. At high slips and low voltages, the motor current is abnormally high and the motor dissipates the input as heat instead of converting it to mechanical energy.

As can be seen, between the 4- and 8-second points in Figure 30, the multiple-motor coupling is very slow in restoring the cylinder speed. To further aggravate the situation at reduced cylinder speeds, the cylinder loses its ability to thresh the grain from the straw and to push the straw through the cylinder. Since the material is not pushed on through the cylinder and since more material enters the cylinder, the duration of the overload condition is prolonged. Between the 4- to 8-second points the majority of the power at the cylinder is used to overcome the friction of the packed material.

Since a prolonged overload condition prevents the coupling from restoring the cylinder speed, Figure 30 the next slug at the 9-second point puts the coupling into an even more inefficient state. At the 10-second point the cylinder speed drops to such an extent that the coupling delivers very little power to the cylinder. The motor is very close to pull-out torque and an unstable condition. Although the motor continues to lug the load, any additional load probably would result in stopping the motor.

An inspection of the plots for the single-motor coupling reveals that the torque that the single-motor coupling and the multiple-motor coupling delivers to the cylinder is practically the same during the first 4 seconds except for the 4-second point. Figure 30 reveals that the load for the single-motor coupling levels off and allows the coupling to restore the cylinder speed before the second slug enters the cylinder. The difference in the performance of the multiple-motor coupling and the single-motor coupling is due to the increased load on the multiple-motor coupling during the 4th and 9th seconds.

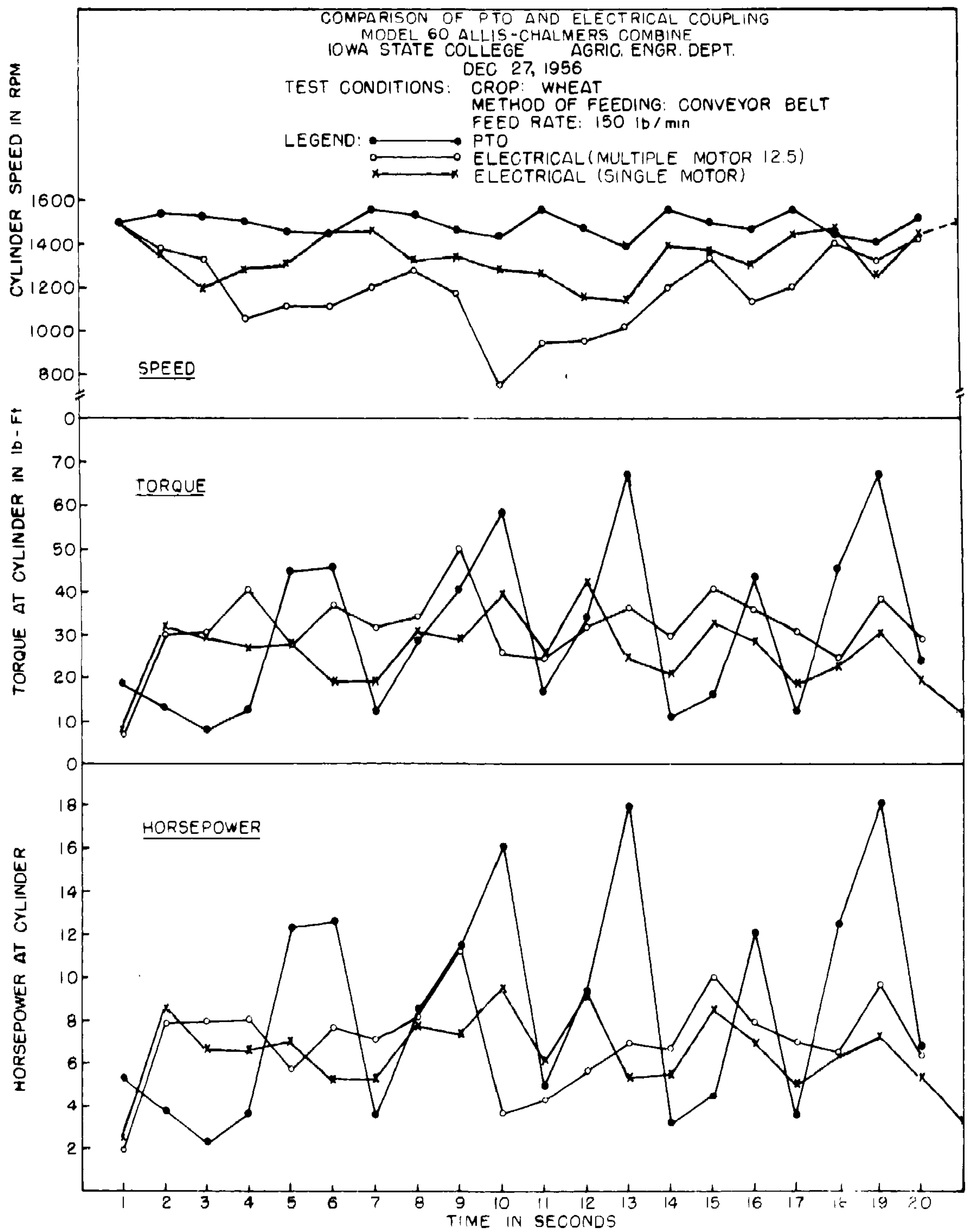
From the time analysis of the charts, it is concluded that the sequence of events which take place in a relatively short time determines the performance of the electrical coupling. If the electrical coupling is to be successful, it must maintain the cylinder speed at a high level during slugging conditions. The mere fact that the cylinder does not jam is no indication that the performance of the coupling is satisfactory.

Figure 31 shows a plot of the time analyses previously presented for the pto, single-motor and multiple-motor couplings (12.5 hp) on the same graph. The plot shows the load pattern (pto torque curve) and the performance of the pto and the electrical couplings.

Slug Study

The slug study was conducted to gain an insight into the

Fig. 31. Comparison of the pto and electrical couplings at a feed rate of 150 lb per min.


COMPARISON OF PTO AND ELECTRICAL COUPLING
MODEL 60 ALLIS-CHALMERS COMBINE
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
DEC 27, 1956
TEST CONDITIONS: CROP: WHEAT
METHOD OF FEEDING: CONVEYOR BELT
FEED RATE: 150 lb/min
LEGEND: PTO
ELECTRICAL (MULTIPLE MOTOR 12.5)
ELECTRICAL (SINGLE MOTOR)
CYLINDER SPEED IN RPM
SPEED
TORQUE AT CYLINDER IN lb-Ft
TORQUE
HORSEPOWER AT CYLINDER
HORSEPOWER
TIME IN SECONDS

performance of the electrical coupling when subjected to high overloads. The pto coupling was used again as a standard in the analysis of the charts. A continuous analysis of the charts was made during the entire overload period. As explained in the procedure, the slugs were manufactured by superimposing several windrows on the original windrow. The results of the study are recorded in Tables XVII and XVIII. Figures 32 and 33 show a time analysis of several typical slugs encountered in the study. The material presented in the graphs represents two different slug intensities and each will be discussed separately.

A comparison of the various plots in Figure 32 reveals that for a slug of a given intensity the duration of the overload period is considerably shorter with the pto coupling than with the electrical couplings. The speed and torque plots follow the same general pattern for all couplings during the first three seconds. At the 3-second point, the power plots of the cylinder is approximately the same for all drives; and the plots of the cylinder speed for both electrical couplings is considerably lower than the plot of the cylinder speed for the pto coupling. The inability of the electrical couplings to push the material on through the cylinder is evident in the duration of the slug. Unless the drive can deliver sufficient power to the cylinder to maintain the cylinder speed during an overload period, the duration of

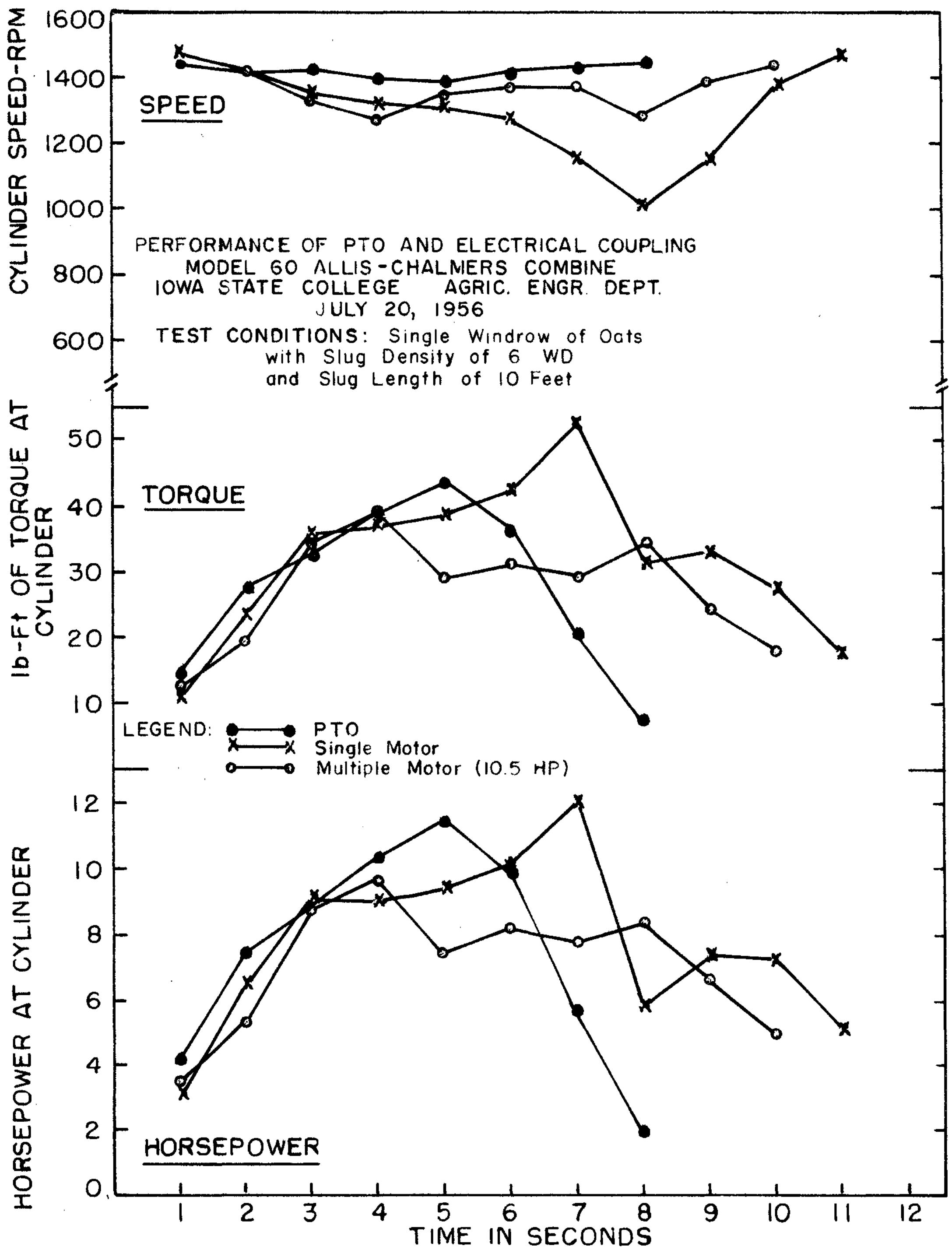


Fig. 32. Performance of the pto, single-motor coupling and the multiple-motor coupling (10.5 hp) under slugging conditions.

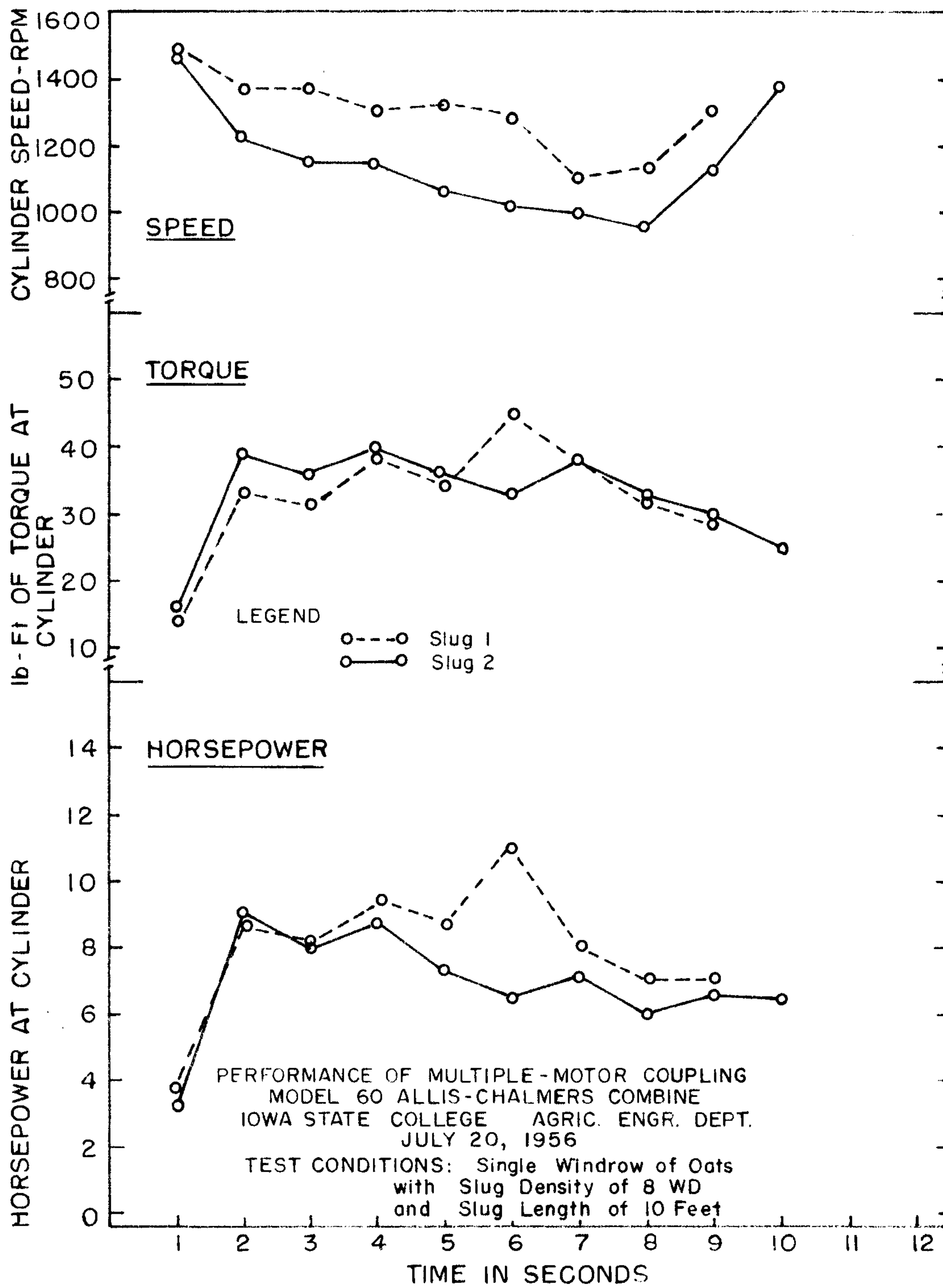


Fig. 33. Performance of the multiple-motor coupling (12.5 hp) under slugging conditions.

the overload period is prolonged as was indicated earlier in the discussion of the stationary load study.

During a prolonged overload period, the cylinder may continue to lose speed or it may begin to increase in speed depending upon how the material continues to enter the cylinder. If there is a discontinuity in the feed flow or the feed rate is reduced, the coupling begins to restore the cylinder speed as shown in the plot of the multiple-motor coupling (10.5 hp) at the 5-, 6 and 7-second points. If the material continues to feed in at the same rate, the coupling continues to let the cylinder speed drop as shown in the plot of the single-motor coupling at the 5-, 6-, 7- and 8-second points. In either case, the overload period is prolonged and the possibility of the cylinder's jamming is always present. The field data which will be presented later indicates that slugging conditions similar to these actually occur during normal combining operations.

Burrough (5) indicates that the power requirements of the cylinder increase much more rapidly than the increase in the feed rate. Therefore, the magnitude of the cylinder load is considerably greater for an 8-windrow slug than for a 6-windrow slug. Figure 33 compares the performance of the multiple-motor (12.5 hp) coupling for two different slugs of the same intensity.

The electrical coupling is not a rigid connection between the engine drive shaft and the load; consequently, more time is required for the governors to respond to the load than with the pto coupling. Since more time is required for the governors to respond, the rate at which the load is increased becomes very important when using electrical couplings. For example, in Figure 33 the torque increases very rapidly during the first second of slug 2 and the cylinder speed decreases very rapidly. Although the torque remains practically constant between the 1- and 5-second points, the speed continues to drop and results in a gradual decrease in the power at the cylinder. In slug 1, the torque increases gradually and the cylinder speed decreases gradually. As a result, more power is delivered to the cylinder during slug 1 than during slug 2 for the entire plot. If the load increases gradually and allows enough time for the governor to respond, the electrical coupling maintains its speed much better than if the load increases rapidly. In the case of a rapid increase in load, the tractor does not start to respond to the overload until after the coupling is in an inefficient condition. As pointed out under the discussion of the stationary load study, the tractor then has a very difficult time restoring the coupling to a state of equilibrium.

In presently designed combines, the slugging action under normal combining operations does not lend itself to the electric drive. As will be pointed out later, part of the slugging in field operations is due to uneven feeding. Consequently, the load increase occurs very rapidly and often results in jamming the cylinder when electrical couplings are used.

Load-Analysis and Performance Study in Windrowed Wheat

In the stationary load study and in the slug study, attempts were made to set up various load levels and high momentary overload periods whereby one could study the performance of the electrical couplings. The two previous studies did not represent field conditions; however, a study of field data will reveal some striking similarities.

The data obtained by stratified sampling of the charts taken in windrowed wheat are presented in Table IXX in Appendix E. The data in the table show that the average load levels of the cylinder range from 6.26 to 8.38 hp. The data for the pickup attachment show that the power demand of the feeding mechanism is only a small portion of the combine load and that the power requirements of the unit remain practically constant.

To gain an insight into the nature and magnitude of the load, a time analysis of the data is necessary. Figure 34 shows a time analysis of the performance of the pto coupling

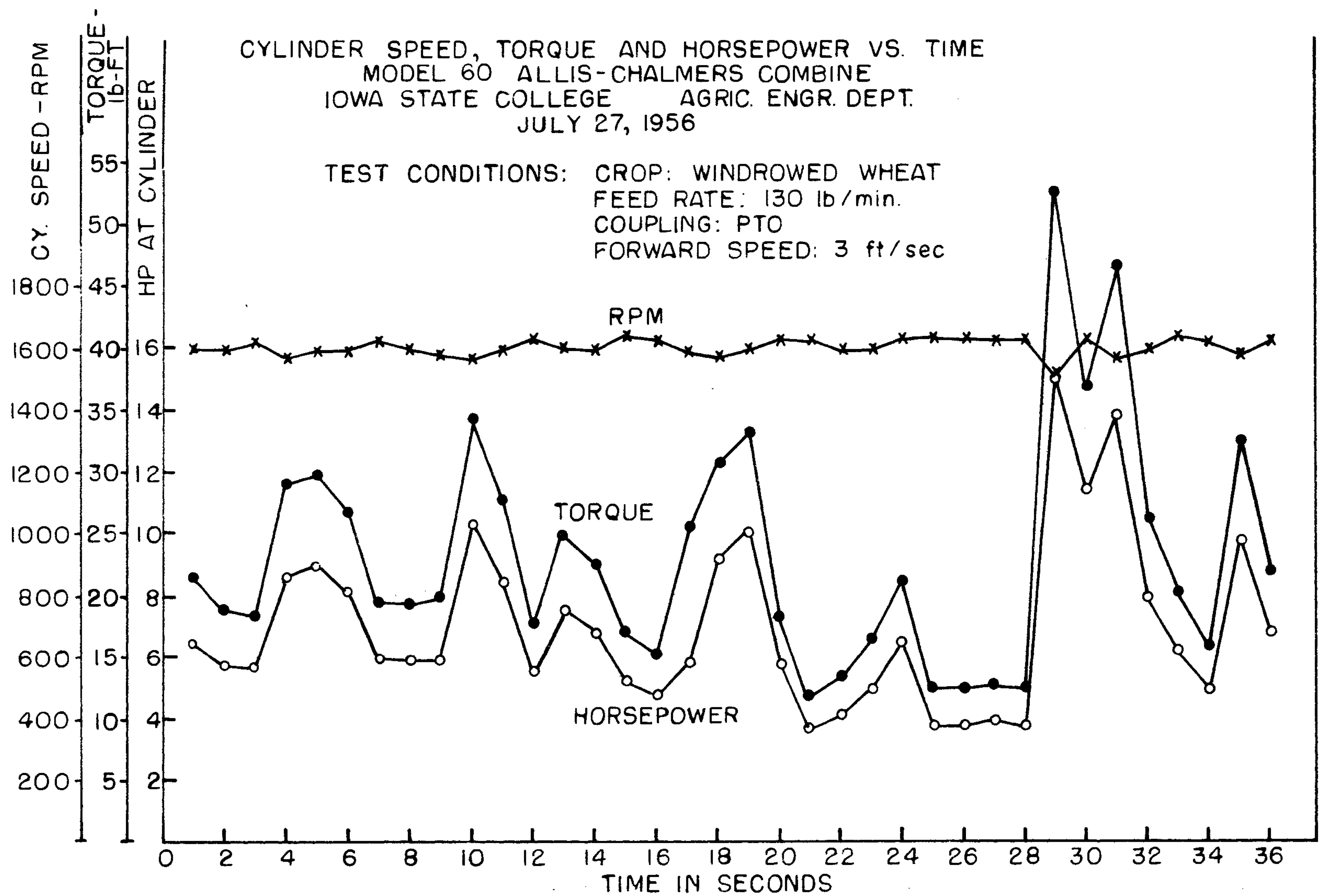


Fig. 34. Cylinder speed, torque and horsepower versus time when combining windrowed wheat.

in windrowed wheat. The data for this plot are recorded in Table XX in Appendix E. An inspection of Figure 34 indicates that the load is far from being a constant load but is characterized by great variations. Further examination of the plot reveals that the torque and power demands of the cylinder increase very rapidly at the beginning of a peak. There is also evidence that the peak loads are caused by uneven feeding of the cylinder. It is particularly evident that during the period between 25 and 28 seconds very little material is entering the cylinder because the load is very light. The region between 28 and 32 seconds indicates a period of very high feed rate. The same evidence of uneven feeding can be seen in the other peak periods; however, it is not quite as pronounced as the 28- to 32-second region.

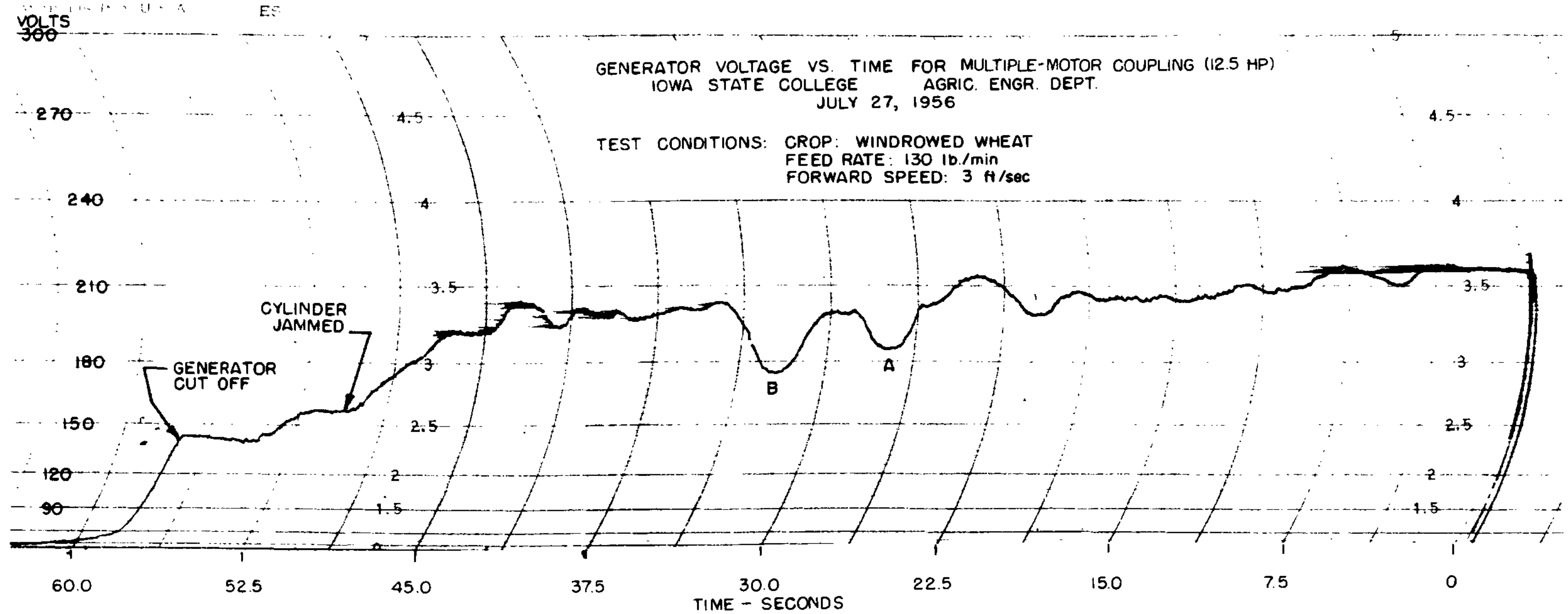
Observations indicate that the uneven feeding is due to the material slipping on the canvas and to the "grabbing" action of the cylinder. The slipping of the material on the canvas causes the material to bunch into large masses. Once the mass of material starts to enter the cylinder, the "grabbing" action of the cylinder pulls the complete mass of the material into the cylinder. It should be noted that some "grabbing" action of the cylinder is necessary for continuous feed flow when the material is not bunching. Other possible causes of peak overloads are green weeds, damp straw or old stubble; however, none of these conditions are responsible for the peak overloads in the study being discussed.

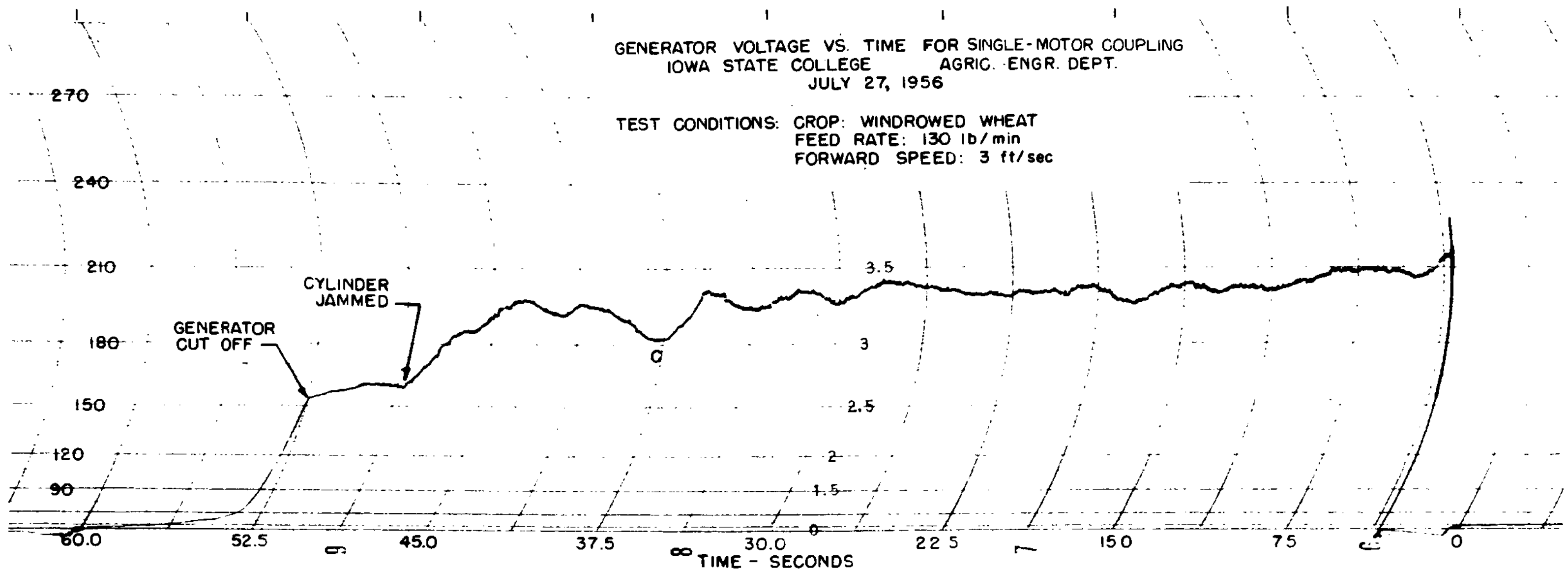
With the nature and magnitude of the cylinder demands established for this particular study, it is interesting to study their effect on the electrical coupling. A study of the voltage charts in Figure 35 indicates the effect of peak overloads on the electrical system. The peak overloads result in lowering the voltage on the generator. Several high momentary overload periods can be seen on the chart; however, points A and B on the multiple-motor coupling and point C on the single-motor coupling are the most severe. The voltage variations on the multiple-motor chart are more extreme than on the single-motor chart. Since the multiple-motor coupling has more motor capacity than the single-motor coupling, the generator is much more likely to become overloaded during peak loads when using the multiple-motor coupling.

As can be seen near the end of both traces, the cylinder jammed and the generator was cut off. Note that in both cases, the voltage was reduced to almost 160 volts at the time of jamming. At points A, B, and C, the voltage was reduced to approximately 180 volts and the system was very near instability. Any additional load at either of these points probably would have resulted in a jammed cylinder.

From the load-analysis and performance study on windrowed wheat, it is concluded that the cylinder load is characterized

Fig. 35. Effect of high momentary overloads on generator voltage.


GENERATOR VOLTAGE VS. TIME FOR MULTIPLE-MOTOR COUPLING (12.5 HP)
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
JULY 27, 1956
TEST CONDITIONS: CROP: WINDROWED WHEAT
FEED RATE: 130 lb./min
FORWARD SPEED: 3 ft/sec
VOLTS
CYLINDER JAMMED
GENERATOR CUT OFF
A
B
TIME - SECONDS


GENERATOR VOLTAGE VS. TIME FOR SINGLE-MOTOR COUPLING
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
JULY 27, 1956
TEST CONDITIONS: CROP: WINDROWED WHEAT
FEED RATE: 130 lb/min
FORWARD SPEED: 3 ft/sec
CYLINDER JAMMED
GENERATOR CUT OFF
C
TIME - SECONDS

by high peak overloads. The pto coupling has the ability to carry through these peaks. The electrical coupling is not a rigid coupling and does not have the ability always to carry through the peak overload periods. The results of the study again point out the necessity of considering the machine design aspects of the problem as well as the electrical design aspects.

Load-Analysis and Performance Study in Soybeans

The results of the study are tabulated in Tables XXI and XXII in Appendix F. The data in Table XXI show that the load level for the cylinder drive is approximately the same for all drive combinations. To get an insight into the nature and magnitude of the loads, a time analysis of the data is necessary. Figure 36 shows a time analysis (data in Table XXII) of the pto coupling and the multiple-motor coupling (12.5 hp) during a typical overload period.

As indicated earlier, the throttle setting of the tractor was maximum because the electrical couplings would not carry through the peak overload periods at the reduced throttle setting. With the reduced cylinder speed (300 to 500 rpm for the particular combine used) necessary for combining soybeans, considerably more torque is necessary to deliver a given horsepower to the cylinder. Since the flywheel action of the

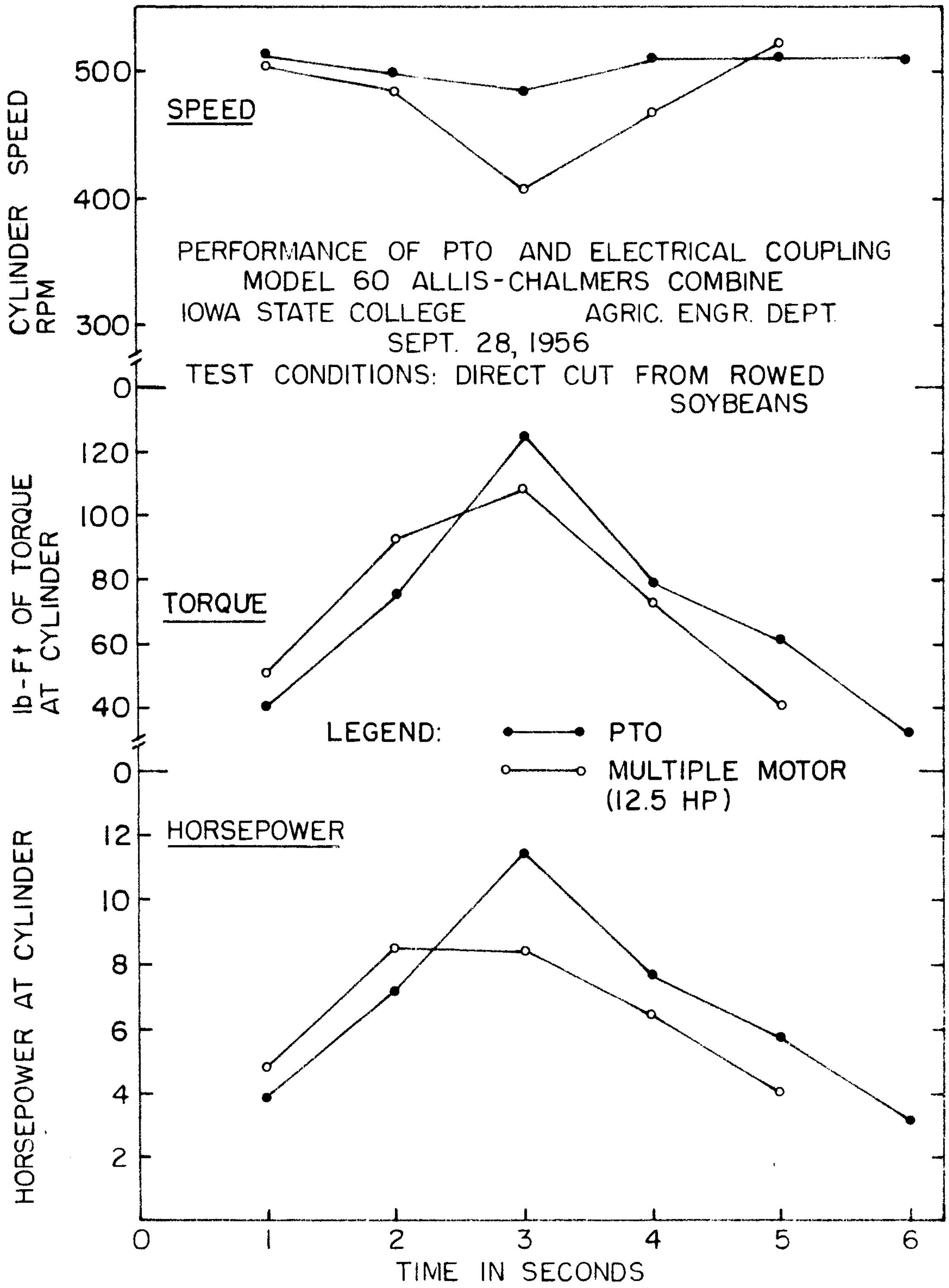


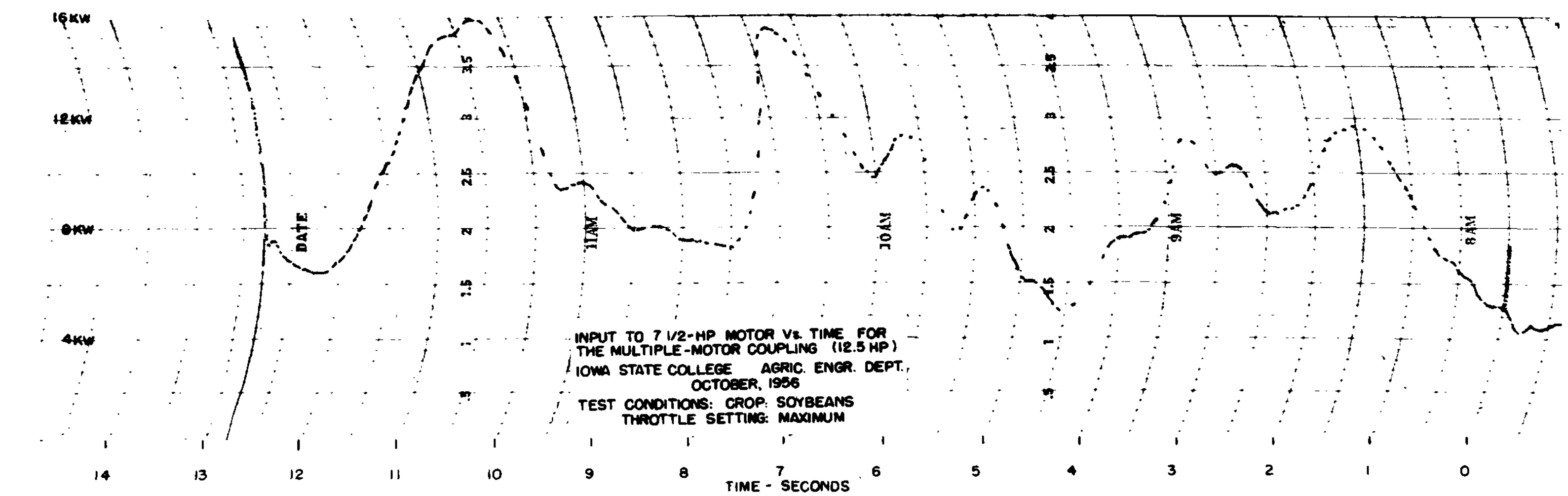
Fig. 36. Performance of pto and the multiple-motor coupling (12.5 hp) when combining soybeans.

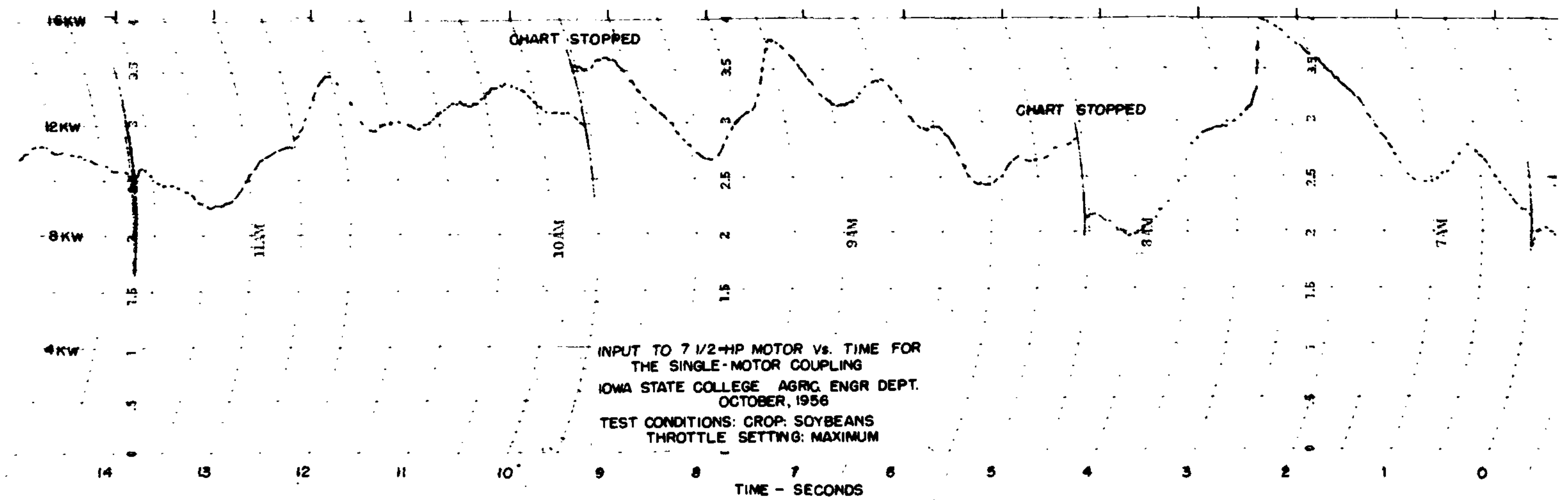
cylinder is reduced, cylinder jamming is much more likely during a sudden overload.

Figure 37 shows the variation of the power demands for the 7.5-hp motor when it is driving the entire machine and when it is driving the cylinder alone. A comparison of the two demand charts reveals that the cylinder is the controlling factor. The top chart shows that the demands of the cylinder drive are characterized by extreme variations. Although the variations in the motor demands are not as extreme when the single motor is driving the entire machine, they are nevertheless present as can be seen in the chart for the single-motor coupling.

Another point worth noting in comparing the charts is the difference between the profile of the peak periods. With the 7.5-hp motor driving the cylinder only, the duration of the peak periods is less than the duration of the peak periods when the 7.5-hp motor is driving the entire machine. This indicates that the performance of the electrical coupling is improved by the use of multiple motors. Since the multiple-motor coupling has a greater motor capacity, it operates in a more efficient state during the overload (provided the generator is not overloaded) and consequently has the ability to push material through the cylinder faster.

Fig. 37. Variation of the power demand for the 7.5-hp motor when driving the entire machine and when driving the cylinder alone.


16KW
12KW
8KW
4KW
DATE
11AM
10AM
9AM
8AM
INPUT TO 7 1/2-HP MOTOR Vs. TIME FOR THE MULTIPLE-MOTOR COUPLING (12.5 HP)
IOWA STATE COLLEGE AGRIC. ENGR. DEPT., OCTOBER, 1956
TEST CONDITIONS: CROP: SOYBEANS
THROTTLE SETTING: MAXIMUM
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
TIME - SECONDS


16KW
12KW
8KW
4KW
CHART STOPPED
CHART STOPPED
11AM
10AM
9AM
8AM
7AM
INPUT TO 7 1/2-HP MOTOR Vs. TIME FOR THE SINGLE-MOTOR COUPLING
IOWA STATE COLLEGE AGRIC. ENGR DEPT. OCTOBER, 1956
TEST CONDITIONS: CROP: SOYBEANS
THROTTLE SETTING: MAXIMUM
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
TIME - SECONDS

Laboratory Study of Power Loss in the Cylinder Drive

This study was conducted to determine the drive efficiency of the cylinder drive at different load conditions. As indicated in the procedure, the drive efficiency was calculated by use of the following relationship:

$$\text{Eff} = \frac{\text{Hp at cylinder strain gage}}{\text{Hp at motor shaft}} \times 100$$

The results of the study are presented in Figure 38 and the data are recorded in Table XXIII in Appendix G.

As can be seen in Figure 38, the drive efficiency varies from 65 to 75 per cent under normal combine operations. This statement is based on the assumption that the average power demand of the cylinder in most combine operations would be between 5.5 to 12.0 hp depending upon the crop and crop conditions. There are extreme variations which do not fall within this range; however, these figures represent average values and are not intended to include all the extreme values. The drive includes the v-belt connection from the motor, the gear box and a second v-belt connection. (See Figure 8.)

If one assumes that the power loss in the universal joints of the pto is the same as the power loss in the v-belt drive connecting the motor to the combine, Figure 38 also represents the drive losses of the combine when the pto is driving the machine. According to Maleev and Hartman (13),

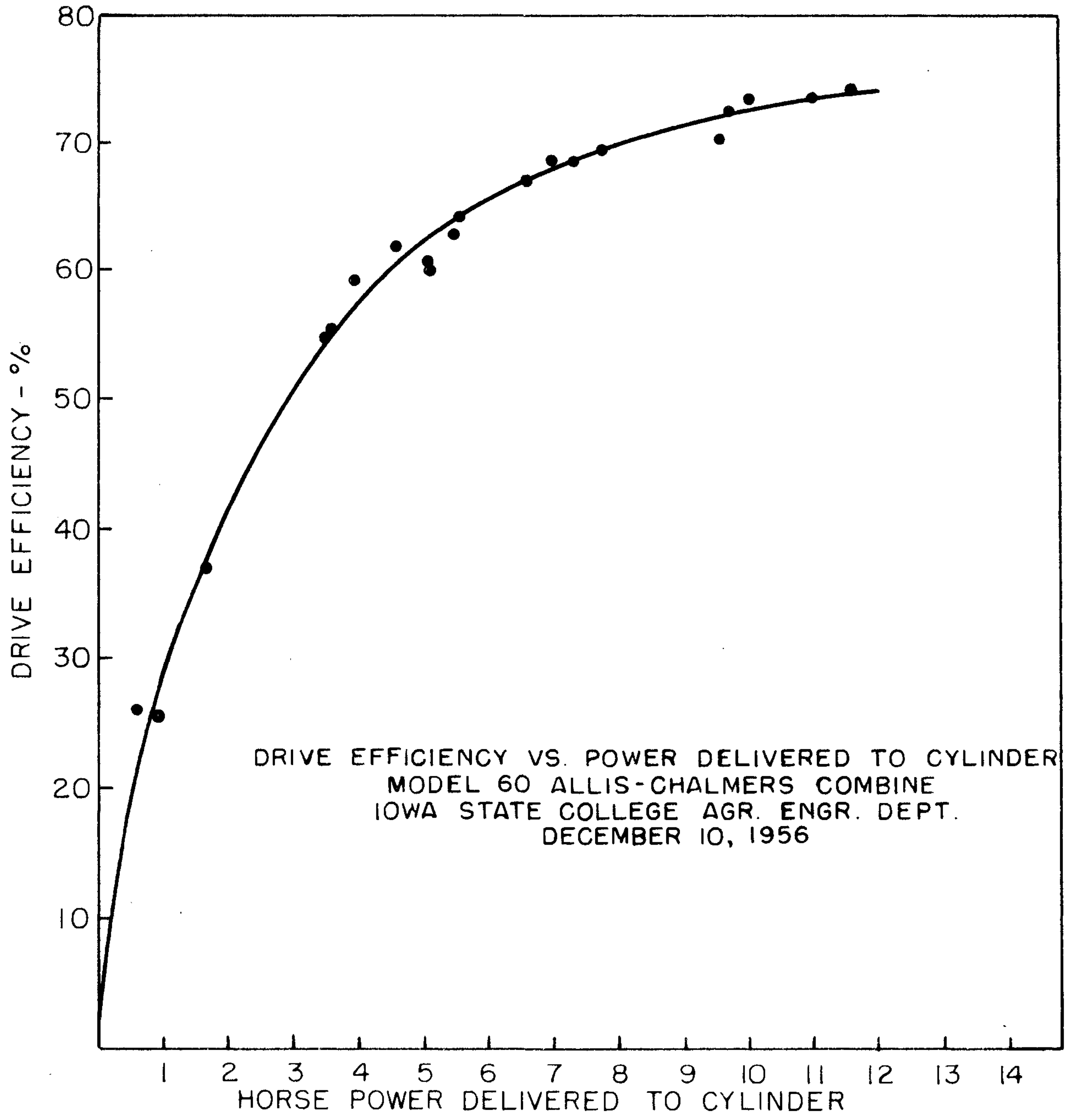


Fig. 38. Drive efficiency of the cylinder drive versus horsepower delivered to the cylinder.

an efficiency of 98 per cent can be expected for a properly aligned v-belt connection and an efficiency of 96 to 98 per cent can be expected for properly aligned double universal joints. This indicates that the assumption concerning the efficiency of the pto connection and v-belt connection is reasonable. Therefore, Figure 38 also represents the cylinder drive efficiency when the combine is being driven by the pto.

Although no data are available on drive efficiency to the other load centers, it should be noted that the power train (when driven from a central drive) is essentially the same as that for the cylinder drive. Thus, it is concluded that the total drive losses in the machine represent 25 to 35 per cent of the total power transfer. The average efficiency is probably around 30 per cent.

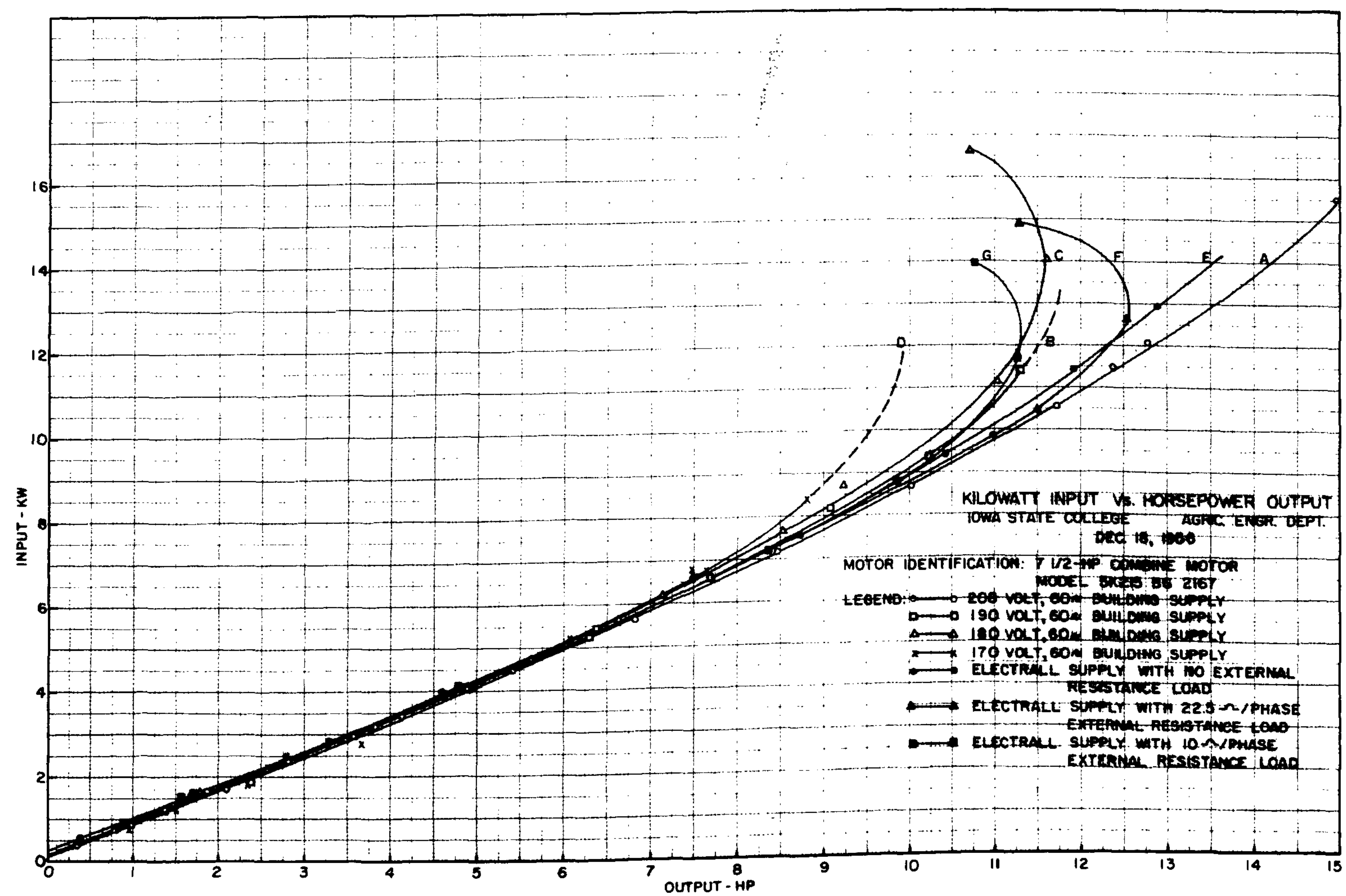
The high drive losses characterizing presently designed combines make it imperative that the combine be designed so as to eliminate some of the losses if the electrical couplings are to be satisfactory. As indicated in the introduction, an efficiency of 65 to 70 per cent can be expected from the electrical coupling. Decentralization of drives could put the electrical coupling on a competitive basis with the mechanical coupling in so far as losses are concerned and at the same time offer many possibilities for machine simplification.

Laboratory Study of the Electrical Coupling under High Overloads

The purpose of the laboratory study was to demonstrate the reduction in maximum overload capacity of the 7.5-hp motor when supplied from a limited power source. The loads were applied gradually by means of an electric dynamometer; consequently, the tractor governors had time to respond to the load when the motor was driven by the generator. Approximately 25 seconds were required to obtain the necessary readings for each data point. The results of the study are presented in Figure 39 and the data are tabulated in Tables III and IV in Appendix B.

An inspection of curves A, B, C and D in Figure 39 reveals that the overload capacity of the motor is reduced when the supply voltage is reduced and the frequency remains constant. An inspection of curves E, F and G shows how the overload capacity of the motor is reduced when powered from a limited power source as compared with curve A which is from the 208-volt, 60-cycle building supply (an "unlimited source"). In curves E, F and G, the tractor throttle setting is the same as that used in the stationary load study. A comparison of curves A and E indicates that the overload capacity of the 7.5-hp motor is not reduced to any great extent when only the motor is connected to the generator. This indicates that the 7.5-hp motor does not have the capacity to overload the

Fig. 39. Kilowatt input versus horsepower output for the 7.5-hp motor when supplied from various power sources.


KILOWATT INPUT Vs. HORSEPOWER OUTPUT
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
MOTOR IDENTIFICATION: 7 1/2-HP COMBINE MOTOR
LEGEND:
208 VOLT, 60~ BUILDING SUPPLY
190 VOLT, 60~ BUILDING SUPPLY
180 VOLT, 60~ BUILDING SUPPLY
170 VOLT, 60~ BUILDING SUPPLY
ELECTRALL SUPPLY WITH NO EXTERNAL RESISTANCE LOAD
ELECTRALL SUPPLY WITH 22.5 Ω/PHASE EXTERNAL RESISTANCE LOAD
ELECTRALL SUPPLY WITH 10 Ω/PHASE EXTERNAL RESISTANCE LOAD
INPUT - KW
OUTPUT - HP
A
B
C
D
E
F
G

generator when used alone.

This test explained why the performance of the electrical coupling during overloads was not improved by the use of multiple-motor drives. The results of the stationary load study indicated that the performance of the electrical coupling under sustained overloads was not improved by the use of the multiple-motor drives. The multiple-motor coupling (12.5 hp) increased the motor capacity of the system from 7.5 to 12.5 hp. If the motors were supplied from an infinite bus, the overload capacity of the coupling would be increased by the same ratio as the motor capacity. In the stationary load study, the addition of the 2- and 3-hp motors acted like the additional resistance load. Since the output of the generator was limited, the addition of the resistive load or of the other motors resulted in overloading the generator. Consequently, under high overload conditions, the performance of the electrical coupling was not improved by the use of multiple motors.

Tests also were made on the 2- and 3-hp motors at reduced frequency and voltage. The data for these tests are recorded in Tables V and VI and presented graphically in Figures 40 and 41 in Appendix B.

DESIGN RECOMMENDATIONS

The success of the electrical coupling depends not only upon proper electrical design but also upon proper machinery design. The design of the electrical system and the design of the field machine must be such that the two complement each other. Further application and testing of electrical couplings without considering both factors will only serve to reproduce the same results as the study being discussed. The design of the electrical system must be based on a study of the load characteristics of the farm machine, and the design of the farm machine must be such that it will lend itself to the application of electrical couplings.

Simplification of the power train is a necessity on such machines as combines. The losses in the various drive mechanisms represent 25 to 35 per cent of the total power transfer on many presently designed combines. Through decentralization of the drives and the use of multiple-motor couplings, part of the drive losses can be eliminated. This would put the overall efficiency of the electrical coupling on a more competitive basis with the pto coupling.

On machines which have great load fluctuations, the addition of a flywheel is a necessity for proper operation of electrical coupling. The addition of properly designed fly-wheels would permit the electrical coupling to operate at a higher level of efficiency during the overload periods. The possibility of reaching an unstable condition would be greatly reduced.

Farm machinery design must be such that the feed rate will be as even as possible. Irregular feeding is a major cause of peak overloads on such machines as combines. The nature of the peak loads caused by uneven feeding is such that it is very detrimental to the performance of an electrical coupling. The increase in load occurs very rapidly and often results in putting the electrical coupling into an inefficient state before the tractor has had time to respond.

In the design of the electrical system, special consideration must be given to the design of the magnetic circuit of the generator. Since the size of the generator is limited, the generator also will be subjected to high peak overload periods. The magnetic circuit must be designed with sufficient capacity to permit the voltage regulator to correct for the IR voltage drops and the drop due to armature reaction. Saturation of the magnetic circuit during overloads results in reducing the effectiveness of the voltage regulator.

The tractor governor should be controlled by a frequency sensing device so that the frequency of the generator output will remain constant. The flyball-type governor used on present day tractors makes it necessary for the tractor to slow down before the throttle is adjusted. This results in lowering the frequency output of the generator and consequently the base speed of the motors. The reduction in generator speed also has a tendency to offset the effect of the voltage regulator. If the generator was driven at a constant speed, the electrical coupling would maintain the speed of the driven machine at a much higher level.

As pointed out above, the peak loads experienced by the motor can be smoothed out somewhat by the addition of a flywheel to those load centers where severe load fluctuations are encountered and by smoothing out the feed flow of the machine. The generator output can be maintained at a much higher level during peak loads by controlling the tractor speed by means of a frequency sensing device. Consequently, motor selection can be based on average power demands of the load center instead of the peak demands of the load center. This would insure more efficient power transfer through the electrical coupling and would improve its overall performance.

The electrical coupling tested was an a-c system; consequently, no discussion has been devoted to a d-c system. Since the d-c system provides excellent possibilities for independent speed control of motors and also has very high starting torques and good lugging ability under overloads, further consideration should be given to the possibility of developing a d-c coupling. The cost of a d-c system would be somewhat higher than an equivalent a-c system and a straight d-c system would not permit the use of standard motors found on the farmstead. Although these are serious disadvantages, the advantage of independent motor control on multiple-motor couplings and the ability to develop high starting torques and good lugging ability might outweigh the disadvantages associated with the system.

SUMMARY AND CONCLUSIONS

Performance studies were made on the International Harvester Electrall system to determine design criteria for electrical couplings for field machines. A model 60 Allis-Chalmers combine was used as the basic loading device. The combine was instrumented so that speed, torque and power could be obtained for the three basic load centers of the machine. (See Figure 8.) Particular attention was given to a time analysis of the combine performance. Electric motors were mounted on the combine so that the machine could be driven by a single-motor coupling, a multiple-motor coupling or the standard pto (power-take-off) coupling. Recording wattmeters and a recording volt meter were used for recording electric parameters.

The study included both field and laboratory tests. The field tests were conducted in windrowed wheat and oats and in rowed soybeans. Stationary loading tests were conducted by feeding the combine by means of a conveyor belt. In the laboratory, the drive losses of the combine were studied and the performance of the electrical coupling under high overloads was studied.

Under regular cyclic loads, such as those found on the feeding and cleaning units of the combine, the performance of the electrical couplings is comparable to the performance of the pto coupling. This type of load does not exist on the major drive center of the combine, that is, the cylinder drive. The cylinder load is characterized by high momentary overloads. The electrical couplings used do not have the ability to maintain cylinder speed under these conditions. The limited output of the generator and the poor governor response together make it impossible to obtain the high overload capacity that one usually associates with electric motors.

On any system with limited generator output, voltage fluctuations are present when the load fluctuates. The voltage fluctuations are generally smoothed out by means of a voltage regulator. With a tractor-mounted generator, the voltage regulator must not only account for the increased IR drop and the armature reaction as the load is increased but it also must take into account decreased generator speed since the tractor must slow down to pick up the load. This results in the generator voltage dropping when overloads are suddenly applied. In addition, the decreased generator speed reduces the output frequency and results in the base speed of the motors being reduced. The electric motor must slip or reduce its speed to pick up the load. This, coupled with the voltage drop and decreased generator speed prevents the motor from developing its normal overload torque without an appreciable speed decrease. This often results in the motor reaching an unstable condition before the load decreases.

Field studies indicate that many of the conditions which result in the jamming of the cylinder are due to poor feeding. Slug studies indicate that a slug which occurs suddenly when the tractor is under light load is more detrimental to the performance of the electrical system than a slug which builds up gradually and allows time for the governor system of the tractor to respond. The sudden overload which occurs because of uneven feeding often causes the slip to increase so rapidly that the electrical coupling becomes extremely inefficient before the tractor governor responds to the load. Once in this state, it is very difficult for the tractor to restore the coupling to a state of equilibrium since the losses in the electrical system are out of proportion to the power transferred through the system. The pto drive, which affords an almost rigid coupling between the load and the tractor, will respond to the sudden overload because the governor response is much quicker and the coupling remains efficient during the overload. In future studies consideration must be given to smoothing out the feed flow and to developing a frequency sensing device for controlling the tractor speed.

From the studies conducted, the following conclusions were drawn:

A Performance of the electrical system tested

1. Speed regulation of the electrical couplings was poor compared to the pto coupling.

2. Under suddenly applied overloads, the electrical couplings did not "carry through" satisfactorily and often resulted in the cylinder becoming jammed.

3. The response time of the governing system of the tractor was too slow when the electrical couplings were subjected to suddenly applied overloads. That is, the electrical system reaches an inefficient condition before the tractor started to restore the electrical system to a state of equilibrium.

4. The performance of multiple-motor couplings was superior to the single-motor coupling under normal load conditions. Under extremely heavy load conditions, when the generator became overloaded, no difference was noted in their performance.

B Load characteristics of the combine tested

1. The feed rate determines to a large extent the power requirements of the cylinder drive.

2. The power required to drive the cylinder is characterized by high momentary overloads.

3. The feed rate has very little effect on the power required to drive the separating and feeding units.

4. Many of the overload conditions which result in jamming the cylinder are due to uneven feeding of the material into the cylinder.

5. Drive losses represented 25 to 30 per cent of the total power transfer.

C Design recommendations for application of electrical couplings to field machines

1. Simplification of the power train is a necessity on machines such as combines if the drive losses are to be reduced.

2. The addition of a flywheel is a necessity where high load fluctuations are encountered with electrical couplings.

3. Consideration must be given to smoothing out the feed flow in order to reduce peak overload periods on machines such as combines.

4. The magnetic circuit of the generator must be designed with sufficient capacity to permit the voltage regulator to correct for the IR voltage drop and the drop due to armature reaction. Saturation of the magnetic circuit during overloads results in reducing the effectiveness of the voltage regulator.

5. The tractor governor should be controlled by a frequency sensing device so that the frequency of the generator output will remain constant.

SELECTED REFERENCES

1. Albers, John. Standby AC power generation on the farm. Wincharger Corporation, Sioux City, Iowa. ⌐Circa 1953¬ ⌐Mimeo. rept.¬

2. Berry, J. H., and Callum, C. L. Speed fluctuations in multijoint power lines. Agr. Engr. 34: 308-11. 1953.

3. Blalock, G. C. Principles of electrical engineering. McGraw Hill Book Company, New York, New York. 1936.

4. Bockhop, Clarence W. Power distribution and requirement of a flail type forage harvester. Unpublished M. S. thesis. Ames, Iowa. Iowa State College Library. 1955.

5. Burrough, D. E. Power requirements in combine drives. Agr. Engr. 35: 15-18. 1954.

6. Burrough, D. E. Power and torque distribution in farm machine drive shafts. Agr. Engr. 34: 382-4. 1953.

7. Dobie, W. B., and Isaac, P. C. Electric resistance strain gages. The English University Press, Ltd., London. 1948.

8. Fitzgerald, A. E., and Kingsley, C. Electric machinery. McGraw Hill Book Company, New York, New York. 1952.

9. Hubert, C. A. Looking ahead with the "Electrall". Paper presented to the American Society of Agricultural Engineers. Chicago, Ill. 1954. ⌐Mimeo. rept.¬

10. Kerchner, R. M., and Corcoran, G. F. Alternating current circuits. John Wiley and Sons, New York, New York. 1953.

11. Kimmich, E. G., and Roesler, W. Q. Variable speed v-belt drives for farm machines with discussion. Agr. Engr. 31: 334-40. 1950.

12. Lukens, A. F. Design considerations for a farm tractor generator. Paper presented to the Farm Electrification Conference, American Institute of Electrical Engineers. Schenectady, N. Y. 1955. ⌐Mimeo. rept.¬

13. Maleev, V. L., and Hartman, J. B. Machine design. International Textbook Company, Scranton, Pennsylvania. 1955.

14. Murray, C. D. Phase I Report on No. 76 Harvester Thresher Electrall. Report presented to International Harvester Company. East Moline, Ill. Sept. 15, 1955. [Mimeo. rept.]

15. Portable electric motors, their selection and care. Rural Elec. News 17: 16-17. 1952.

16. Pumpheny, F. H. Electrical engineering. Prentice-Hall, Inc., New York, New York. 1947.

17. Shoults, D. R., Rife, J. C., and Johnson, T. C. Electric motors in industry. John Wiley and Sons, New York, New York. 1953.

18. Stewart, E. A. Cutting ensilage with electric motors. Agr. Engr. 9: 175-9. 1928.

19. Wagner, C. P. Motor size confusion hinders farm service development. Electrical World 131: 168-71. 1949.

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APPENDICES

Appendix A: Calibration Data for
Shafts of Model 60 Allis-Chalmers Combine

Table II. Calibration data for shafts on Model 60 Allis-Chalmers combine

Attenuator	Sensitivity (lines)	Date	Torque (lb-ft)	No. of lines deflection	No. of lines (Attenuator setting of 1)
			Knife and canvas shaft		
2	15	8/15/55	11.76	8.40	16.80
			17.72	12.80	25.60
			20.70	15.00	30.00
			29.64	21.60	43.20
2	15	10/7/56	15.00	11.00	22.00
			30.00	22.00	44.00
			36.00	26.00	52.00
			Main separator shaft		
5	15	10/7/56	6.00	1.40	7.00
			15.00	4.20	21.00
			21.00	6.00	30.00
			30.00	9.00	45.00
5	15	10/15/56	8.80	2.70	13.50
			10.80	3.10	15.50
			10.90	3.40	17.00
			12.10	3.60	18.00
			12.40	3.60	18.00
			17.90	5.30	26.50
			18.40	5.60	28.00
			24.60	7.60	38.00
5	15	12/5/56	15	4.50	22.50
			30	9.00	45.00
			45	13.25	66.25
			60	17.75	88.75
			Cylinder shaft		
2	15	12/5/56	15	2.00	4.00
			30	4.00	8.00
			45	6.00	12.00
			60	8.00	16.00
			75	10.00	20.00
			87	11.25	22.50

Formulae used in calculations

In calculating the horsepower obtained from the strain-gage charts, several formulae were used.

The torque was calculated by the following formula:

$$T = \frac{AS}{L} \times \text{Atn. Setting of Instrument}$$

Where A - Area obtained by planimetering the charts $(mm)^2$

S - Slope of calibration curve $\left(\frac{lb\text{-}ft}{mm}\right)$

L - Length of chart sampled (mm)

$$T = \frac{A(mm)^2 \; S\left(\frac{lb\text{-}ft}{mm}\right)}{L\ (mm)} \times \text{Atn. Setting} = \text{Torque in lb-ft}$$

The horsepower was calculated by the following relationship:

$$Hp = \frac{T(lb\text{-}ft) \times N(rpm) \times 2\pi\,(rad/rev)}{33{,}000}$$

Appendix B: Motor Performance Characteristics Data

Table III. Performance characteristics of the 7-1/2-hp combine motor[1]

	Motor data				Dynamometer data[2]			Motor
Volts	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
208	9.23	400	3325	0.12	1.25	1795	0.37	69.0
	9.73	880	3505	0.25	3.40	1790	1.01	85.6
	9.73	1000	3505	0.29	3.95	1790	1.18	88.0
	10.39	1600	3743	0.42	6.25	1785	1.86	86.7
	10.75	1710	3873	0.44	7.00	1785	2.08	90.7
	11.51	2320	4147	0.56	9.45	1780	2.80	90.0
	13.07	3200	4709	0.68	12.90	1775	3.81	88.8
	13.70	3400	4936	0.69	13.95	1770	4.11	90.2
	16.00	4450	5764	0.77	18.25	1770	5.38	90.2
	19.76	5640	7119	0.79	23.25	1750	6.78	89.7
	24.06	7200	8668	0.83	29.15	1740	8.45	87.6
	28.30	8700	10195	0.85	34.90	1715	9.98	85.6
	32.22	10600	11607	0.91	41.25	1700	11.69	82.1
	36.40	11560	13113	0.88	44.25	1675	12.35	79.7
	38.70	12080	13942	0.87	45.85	1670	12.76	78.8
	49.50	15500	17823	0.87	55.70	1610	14.95	72.0
190	8.10	400	2666	0.15	1.25	1792	0.37	69.0
	9.00	1200	2962	0.41	4.75	1790	1.42	88.3
	10.14	1840	3337	0.55	7.35	1785	2.19	88.8
	12.55	2920	4130	0.71	12.10	1775	3.58	91.5
	15.98	4000	5259	0.76	16.55	1764	4.87	90.8
	19.66	5280	6470	0.82	21.55	1750	6.29	88.9
	20.00	5400	6582	0.82	21.85	1745	6.35	87.6
	23.72	6600	7806	0.85	26.65	1730	7.68	86.8
	28.10	8080	9247	0.87	31.85	1705	9.05	83.6
	34.70	9400	11419	0.82	36.45	1680	10.20	80.9
	42.85	11400	14101	0.81	42.35	1632	11.52	75.4

[1] Motor model no. 5K215BG2167.
Source: Three-phase, 60-cycle infinite bus.
Date: 12/3/56.

[2] Dynamometer hp = $\frac{\text{lb x rpm}}{6000}$.

Table III. (Continued)

	Motor data				Dynamometer data[2/]			Motor
Volts	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
180	7.57	400	2360	0.17	1.25	1795	0.37	69.1
	7.92	720	2469	0.29	2.75	1790	0.82	87.1
	9.28	1560	2893	0.54	6.15	1785	1.83	87.5
	10.63	2160	3314	0.65	8.75	1772	2.58	89.1
	10.95	2280	3414	0.67	9.25	1780	2.74	89.7
	12.45	2880	3881	0.74	11.80	1770	3.48	90.1
	18.56	4720	5786	0.82	19.25	1745	5.60	88.5
	21.44	5640	6684	0.84	22.85	1735	6.61	87.4
	23.40	6200	7295	0.85	24.75	1725	7.12	85.7
	28.98	7680	9035	0.85	29.95	1700	8.49	82.5
	32.60	8720	10163	0.86	33.00	1675	9.21	78.8
	41.50	11200	12938	0.87	40.75	1620	11.00	73.3
	58.50	14100	18238	0.77	46.15	1505	11.58	61.3
	69.75	16700	21745	0.77	48.15	1330	10.67	47.7
170	6.95	360	2046	0.18	1.25	1795	0.37	76.7
	7.63	800	2247	0.36	3.25	1790	0.97	90.5
	8.37	1240	2464	0.50	5.15	1785	1.53	92.0
	9.73	1840	2865	0.64	7.35	1780	2.35	95.3
	10.75	2200	3165	0.70	8.95	1775	2.65	89.9
	11.65	2480	3430	0.72	9.45	1770	2.79	83.9
	13.13	2800	3866	0.72	12.45	1765	3.66	97.5
	15.80	3920	4652	0.84	15.95	1755	4.67	88.9
	21.00	5200	6183	0.84	20.80	1745	6.05	86.8
	26.36	6680	7761	0.86	26.35	1710	7.51	83.9
	26.40	6720	7773	0.86	26.35	1705	7.49	83.7
	26.60	6800	7832	0.87	26.85	1705	7.63	83.7
	38.20	8400	11248	0.75	31.75	1660	8.78	78.0
	45.50	10000	13397	0.75	34.15	1580	8.99	67.1

Table IV. Performance characteristics of 7-1/2-hp combine motor[1]

Generator data			Motor data				Dynamometer data[2]			Motor
Volts	Watts	Freq.	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
224	0	60.25								
218	480	60.00	10.90	480	4116	0.12	1.35	1775	0.40	62.01
216	1600	59.50	11.60	1600	4340	0.37	5.85	1762	1.72	80.20
214	2840	59.25	13.44	2840	4982	0.57	11.35	1740	3.29	86.42
212	4000	59.00	15.40	4000	5655	0.71	15.95	1730	4.60	85.79
207	7600	58.50	26.08	7600	9350	0.81	31.25	1670	8.70	85.40
204	9480	58.00	31.92	9480	11278	0.84	38.25	1632	10.40	81.84
204	10000	58.00	34.50	10000	12190	0.82	40.25	1634	10.96	81.76
200	11500	57.50	38.80	11500	13440	0.86	44.95	1588	11.90	77.19
198	11900	57.25	43.00	11900	14746	0.81	47.20	1585	12.47	78.17
190	13000	56.50	52.50	13000	17277	0.75	51.75	1490	12.85	73.74
With an additional resistance load of 10 ohms/phase added										
222	0	59.50								
214	4580	58.75								
211	5330	58.75	10.84	880	3961		3.00	1740	0.87	73.75
210	5920	11.40	11.40	1520	4146		5.55	1735	1.60	78.53
206	8280	58.00	15.90	4040	5673		16.85	1695	4.76	87.90
205	9830	57.50	20.88	5640	7414		23.65	1675	6.60	87.30
202	11300	57.50	25.68	7240	8985		30.35	1650	8.35	86.04
198	12720	57.00	31.20	8800	10700		36.65	1610	9.83	83.33
192	15430	56.50	38.40	11750	12770		43.45	1555	11.26	71.49
173	17100	55.00	61.00	14100	18278		49.55	1300	10.74	56.82
With an additional resistance load of 22.5 ohms/phase added										
222	0	59.75								
207	8500	58.00	20.40	5600	7314		22.95	1690	6.46	86.06
204	9120	57.75	25.56	7280	9031		30.20	1660	8.36	85.67
201	10350	57.50	30.48	8300	10611		36.35	1625	9.84	83.42
198	12120	57.00	36.80	10600	12620		43.15	1595	11.47	80.72
191	14170	56.50	47.20	12700	15614		49.25	1525	12.52	73.54
170	16280	54.75	66.00	15000	19433		52.15	1295	11.25	56.00

[1] Motor model no. 5K215BG2167.
Source: Electrall generator.
Date: 12/6/56.

[2] Dynamometer hp = $\frac{\text{lb x rpm}}{6000}$.

Table V. Performance characteristics of 3-hp combine motor[1/]

Freq.	Volts	Motor data Amps	Watts	V-A	P.F.	Dynamometer data[2/] Lb.	Rpm	Hp	Motor eff.%
60	208	10.00	600	3603	0.17	1.25	1780	0.37	46.14
		10.44	1220	3761	0.32	3.85	1765	1.13	69.28
		10.62	1560	3826	0.41	5.30	1755	1.55	74.12
		11.00	2020	3963	0.51	7.25	1745	2.11	77.89
		11.68	2600	4208	0.62	9.65	1725	2.77	79.59
		12.70	3220	4575	0.70	12.05	1710	3.43	79.56
		13.66	3780	4921	0.77	14.25	1690	4.01	79.22
		14.74	4340	5310	0.82	16.25	1660	4.50	77.28
		15.00	4400	5404	0.81	16.60	1665	4.61	78.11
		16.40	5060	5908	0.86	18.85	1630	5.12	75.50
		16.70	5320	6016	0.88	19.65	1635	5.35	75.02
60	180	6.64	400	2070	0.19	1.25	1780	0.37	69.19
		6.90	760	2151	0.35	2.55	1770	0.75	73.81
		7.32	1100	2282	0.48	4.05	1760	1.19	80.57
		7.44	1200	2319	0.52	4.50	1750	1.31	81.62
		8.18	1500	2550	0.59	5.75	1745	1.67	83.15
		8.74	1820	2725	0.67	7.00	1730	2.02	88.72
		9.24	2100	2881	0.73	7.95	1710	2.27	80.50
		9.76	2240	3043	0.74	8.65	1715	2.47	82.33
		12.22	3200	3810	0.84	12.15	1675	3.39	79.08
		12.34	3220	3841	0.84	12.40	1675	3.46	80.21
		15.44	4360	4845	0.90	15.95	1595	4.24	72.55
		18.84	5500	5874	0.94	19.05	1500	4.76	64.60
55	180	8.44	500	2631	0.19	1.15	1625	0.31	46.55
		8.70	1000	2712	0.37	3.50	1610	0.94	70.05
		9.48	1600	2955	0.54	6.25	1585	1.65	76.98
		10.00	1940	3118	0.62	7.75	1570	2.03	77.98
		11.50	2700	3585	0.75	11.15	1550	2.88	79.57
		12.52	3160	3903	0.81	12.85	1525	3.27	77.10
		13.34	3500	4159	0.84	14.10	1510	3.55	75.64
		15.42	4200	4807	0.87	16.95	1470	4.15	73.77
		16.70	4740	5206	0.91	18.55	1440	4.45	70.07
		18.90	5420	5892	0.92	20.90	1390	4.84	66.64

[1/] Motor model no. 5K184BG2613.
Source: Variable-frequency and- voltage alternator, Electrical Engineering Department, Iowa State College.
Date: 11/25/56.

[2/] Dynamometer hp = $\frac{\text{lb x rpm}}{6000}$.

Table V. (Continued)

		Motor data				Dynamometer data[2]			Motor
Freq.	Volts	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
50	180	11.10	620	3461	0.18	1.05	1480	0.26	31.16
		11.34	1240	3535	0.35	4.40	1460	1.07	64.43
		11.62	1740	3623	0.48	6.85	1440	1.64	70.48
		12.36	2300	3853	0.60	9.70	1420	2.30	74.47
		13.30	2980	4146	0.72	12.75	1405	2.99	74.75
		15.40	3960	4801	0.83	17.45	1360	3.96	74.51
		18.20	5060	5674	0.89	21.95	1305	4.77	70.38

Fig. 40. Kilowatt input versus horsepower output for variable voltage and frequency conditions (3-hp motor).

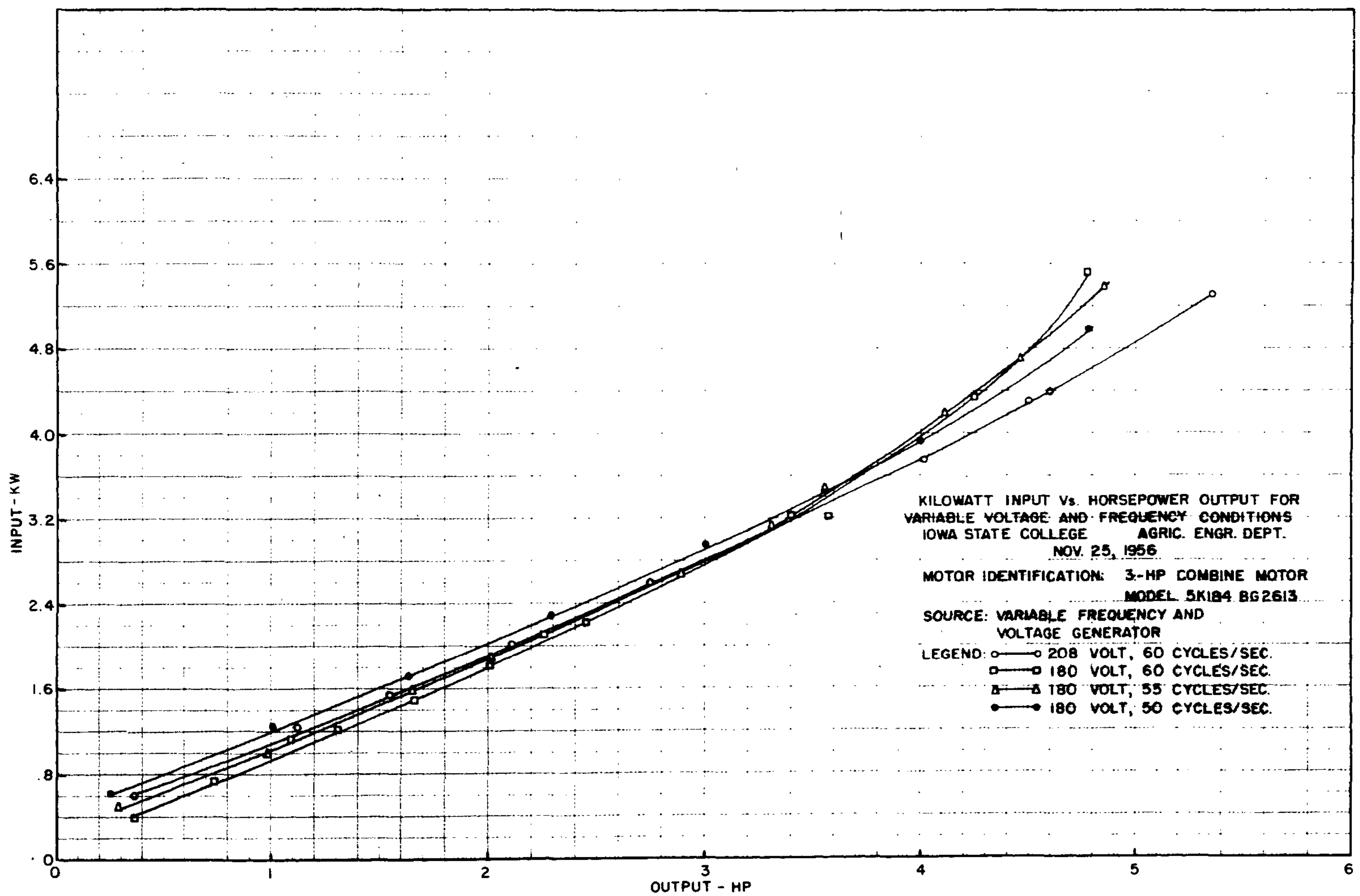

KILOWATT INPUT Vs. HORSEPOWER OUTPUT FOR
VARIABLE VOLTAGE AND FREQUENCY CONDITIONS
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
NOV. 25, 1956
MOTOR IDENTIFICATION: 3-HP COMBINE MOTOR
MODEL 5K184 BG2613
SOURCE: VARIABLE FREQUENCY AND
VOLTAGE GENERATOR
LEGEND: 208 VOLT, 60 CYCLES/SEC.
180 VOLT, 60 CYCLES/SEC.
180 VOLT, 55 CYCLES/SEC.
180 VOLT, 50 CYCLES/SEC.
INPUT - KW
0
.8
1.6
2.4
3.2
4.0
4.8
5.6
6.4
OUTPUT - HP
0
1
2
3
4
5
6

Table VI. Performance characteristics of 2-hp combine motor[1/]

Motor data						Dynamometer data[2/]			Motor
Freq.	Volts	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
60	208	5.41	600	1949	0.31	1.90	1780	0.56	69.63
		5.86	1040	2111	0.49	3.75	1765	1.10	78.90
		6.49	1500	2338	0.64	5.45	1744	1.58	78.58
		7.38	1960	2659	0.74	7.20	1730	2.08	79.17
		10.48	3200	3775	0.85	11.70	1640	3.20	74.60
		11.62	3620	4186	0.86	13.10	1624	3.55	73.16
60	180	4.10	400	1278	0.31	1.30	1780	0.39	72.74
		4.60	780	1434	0.54	2.80	1764	0.82	78.43
		5.82	1280	1814	0.71	4.80	1735	1.39	81.00
		6.84	1640	2132	0.77	6.20	1710	1.77	80.51
		8.10	2080	2525	0.82	7.80	1686	2.19	78.55
		8.84	2360	2756	0.86	8.70	1660	2.41	76.18
		10.70	2940	3336	0.88	10.50	1615	2.83	71.81
55	180	4.35	400	1356	0.29	1.25	1620	0.34	63.41
		5.39	1080	1680	0.64	4.35	1585	1.15	79.44
		6.42	1560	2001	0.78	6.40	1555	1.66	79.38
		8.28	2280	2581	0.88	9.25	1510	2.33	76.24
		9.50	2710	2962	0.92	10.85	1480	2.68	73.77
		11.50	3200	3585	0.89	12.35	1435	2.95	68.77
		12.35	3440	3850	0.89	13.35	1410	3.14	68.09
50	180	5.75	400	1793	0.22	1.20	1475	0.30	55.95
		6.03	940	1880	0.50	3.90	1455	0.95	75.39
		6.75	1360	2104	0.65	5.95	1430	1.42	77.89
		8.80	2300	2743	0.84	10.35	1375	2.37	76.87
		11.70	3220	3336	0.97	13.85	1305	3.01	69.73
		13.10	3660	4084	0.90	15.55	1280	3.32	67.67
		16.50	4760	5144	0.93	18.45	1170	3.60	56.42

[1/]Motor model no. 5K184BG2614.
Source: Variable-frequency and- voltage alternator, Electrical Engineering Department, Iowa State College.
Date: 11/21/56.

[2/]Dynamometer hp = $\frac{\text{lb x rpm}}{6000}$.

Fig. 41. Kilowatt input versus horsepower output for variable voltage and frequency conditions (2-hp motor).

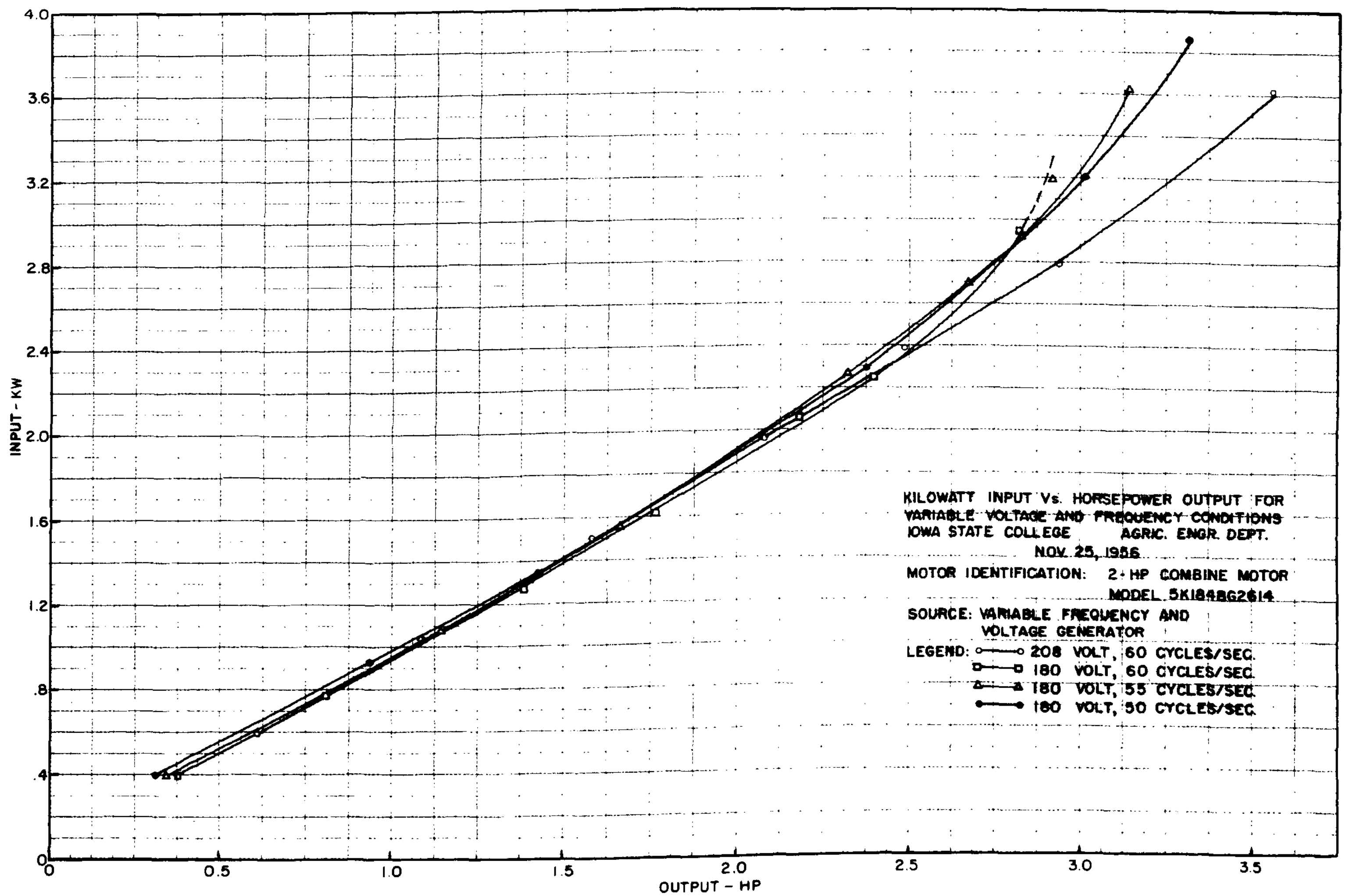

KILOWATT INPUT Vs. HORSEPOWER OUTPUT FOR VARIABLE VOLTAGE AND FREQUENCY CONDITIONS
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
NOV. 25, 1956
MOTOR IDENTIFICATION: 2-HP COMBINE MOTOR
MODEL 5K184BG2614
SOURCE: VARIABLE FREQUENCY AND VOLTAGE GENERATOR
LEGEND:
208 VOLT, 60 CYCLES/SEC.
180 VOLT, 60 CYCLES/SEC.
180 VOLT, 55 CYCLES/SEC.
180 VOLT, 50 CYCLES/SEC.
INPUT - KW
OUTPUT - HP
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

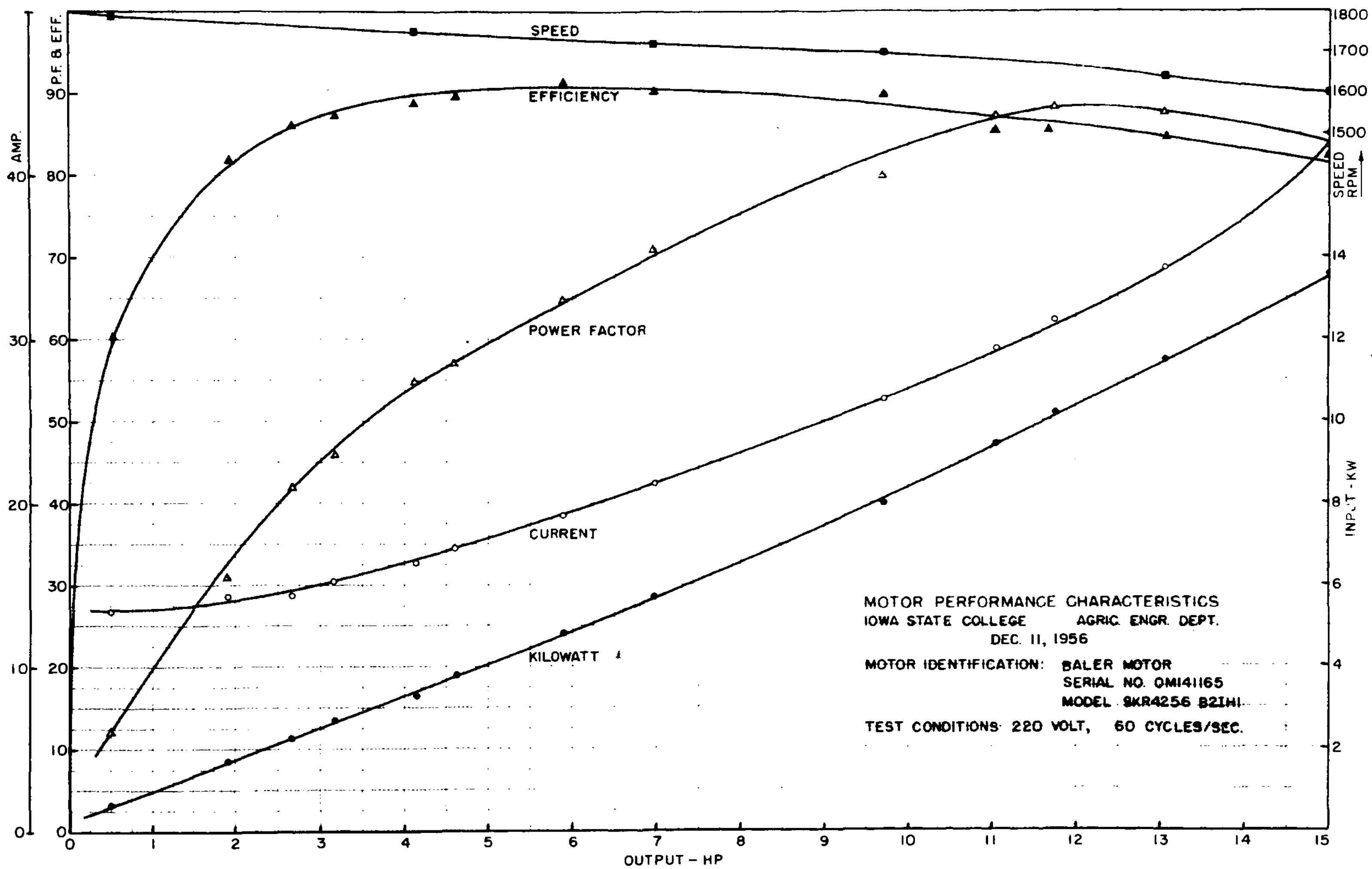
Table VII. Performance characteristics of the 10-hp baler motor[1]

Source data		Motor data				Dynamometer data[2]			Motor
Freq.	Volts	Amps	Watts	V-A	P.F.	Lb.	Rpm	Hp	eff.%
60	220	13.40	600	5106	0.12	1.65	1792	0.49	92.0
	222	14.32	1720	5506	0.31	6.35	1780	1.88	92.0
	220	14.40	2280	5487	0.42	8.95	1770	2.64	95.6
	220	15.28	2680	5822	0.46	10.65	1765	3.14	94.6
	219	16.40	3430	6206	0.55	13.95	1755	4.08	92.8
	220	17.40	3800	6630	0.57	15.75	1745	4.57	89.9
	220	19.28	4800	7346	0.65	20.25	1735	5.86	91.5
	220	21.28	5720	8109	0.71	24.15	1725	6.93	90.5
	220	26.40	8000	10059	0.80	34.05	1700	9.65	90.0
	220	29.56	9520	11264	0.85	39.35	1675	11.00	85.5
	220	31.24	10200	11904	0.86	42.60	1660	11.68	85.5
	220	34.40	11500	13108	0.88	47.45	1642	13.00	84.4
	220	42.50	13600	16194	0.84	56.45	1600	15.00	82.5
60	208	11.50	500	4143	0.12	1.65	1792	0.49	73.0
	208	12.00	1160	4323	0.27	4.45	1778	1.32	85.2
	208	12.16	1440	4381	0.33	5.75	1780	1.71	88.6
	208	12.44	1800	4482	0.40	7.15	1770	2.11	87.1
	208	12.98	2200	4676	0.47	8.75	1770	2.58	87.5
	208	13.60	2620	4899	0.53	10.65	1762	3.13	89.2
	208	14.60	3200	5260	0.61	13.15	1755	3.85	89.7
	208	16.20	4060	5836	0.70	16.75	1742	4.87	89.5
	208	18.40	5140	6629	0.78	21.45	1730	6.18	89.7
	208	21.60	5960	7782	0.77	25.55	1720	7.31	91.5
	208	24.48	7080	8819	0.80	30.35	1700	8.65	91.1
	208	28.40	8720	10231	0.85	36.55	1675	10.20	87.5
	208	36.32	11680	13084	0.89	48.55	1620	13.15	84.0
	208	44.00	13400	15851	0.84	56.35	1572	14.80	82.4

[1] Motor model no. OM141165.
Source: Three-phase, 60-cycle infinite bus.
Date: 12/11/56.

[2] Dynamometer hp = $\frac{\text{lb x rpm}}{6000}$.

Fig. 42. Motor performance characteristics of the motor used for obtaining drive efficiency data.



SPEED
EFFICIENCY
POWER FACTOR
CURRENT
KILOWATT
AMP.
P.F. & EFF.
SPEED RPM
INPUT - KW
OUTPUT - HP
MOTOR PERFORMANCE CHARACTERISTICS
IOWA STATE COLLEGE AGRIC. ENGR. DEPT.
DEC. 11, 1956
MOTOR IDENTIFICATION: BALER MOTOR
SERIAL NO. OM141165
MODEL 8KR4256 B21H1
TEST CONDITIONS 220 VOLT, 60 CYCLES/SEC.

Table VIII. No load voltage and field current of Electrall generator[1]

Field current Amps	No load voltage
2.0	80
2.5	105
3.3	125
3.9	139
4.3	153
5.0	165
6.1	175
8.0	186
9.3	193
10.5	199
13.0	207
15.5	215
17.1	218
19.5	222
21.0	224
21.1	226

[1] Frequency: 60 $\pm$ 0.25 cycles/second.
Drive: International 400 tractor.

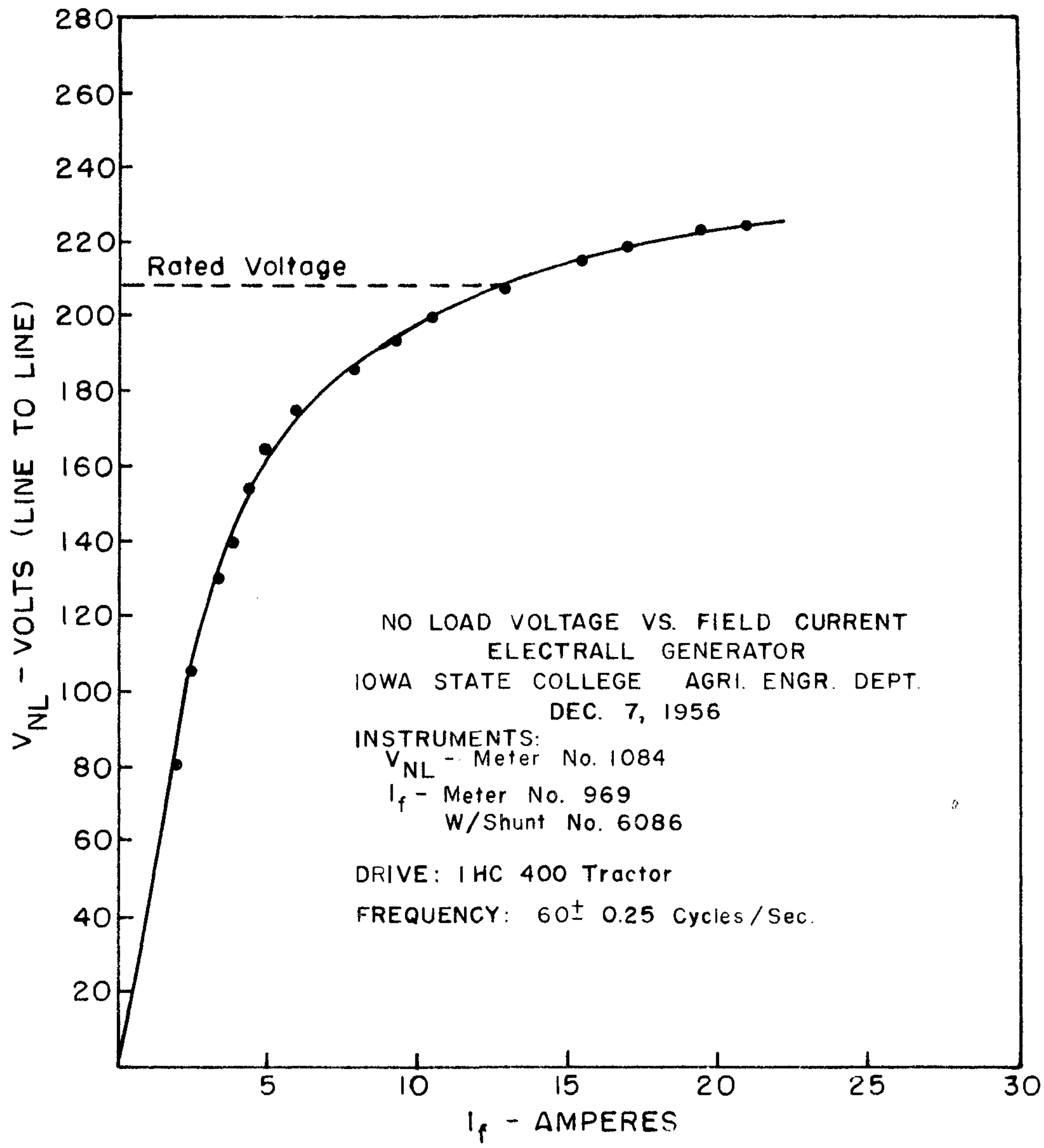


Fig. 43. No load voltage versus field current for the Electrall generator.

Appendix C: Stationary Load Study Data

Table IX. Feed rate, torque, speed and horsepower for the PTO coupling

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Main-separator shaft Torque Lb-ft	Main-separator shaft Speed Rpm	Main-separator shaft Power Hp
75	24.60	1482	6.94	16.10	522	1.60
	12.00	1542	3.52	17.10	546	1.78
	24.00	1476	6.74	15.80	525	1.58
	12.60	1554	3.73	16.35	549	1.71
	26.40	1482	7.45	12.90	522	1.28
	13.20	1554	3.90	17.15	549	1.79
	16.80	1554	4.97	16.90	549	1.77
	19.20	1518	5.55	16.60	528	1.67
	9.00	1539	2.64	15.30	537	1.56
	41.40	1452	11.44	16.10	519	1.59
	19.92	1515	5.74	16.03	535	1.63
100	20.40	1548	6.01	15.70	546	1.63
	42.00	1532	12.25	15.30	522	1.52
	12.36	1506	3.54	17.50	546	1.82
	17.40	1500	4.97	13.70	528	1.38
	23.92	1512	6.88	16.30	550	1.71
	18.04	1554	5.34	17.70	555	1.87
	28.26	1500	8.07	14.80	535	1.51
	35.82	1500	10.23	17.70	540	1.82
	26.70	1506	7.65	15.80	540	1.62
	10.44	1560	3.10	15.80	555	1.67
	23.53	1522	6.80	16.03	542	1.65
125	60.00	1443	16.48	13.40	522	1.33
	24.00	1548	7.07	14.20	552	1.49
	19.80	1506	5.68	13.70	528	1.38
	61.80	1434	16.87	14.20	519	1.40
	21.00	1548	6.19	16.35	555	1.73
	15.60	1518	4.51	16.60	534	1.69
	17.40	1536	3.09	15.70	546	1.63
	43.80	1470	12.25	12.90	522	1.28
	39.00	1521	11.29	15.30	540	1.57
	40.80	1509	11.72	15.55	534	1.58
	34.32	1503	9.82	14.79	535	1.51

Table IX. (Continued)

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Main-separator shaft Torque Lb-ft	Main-separator shaft Speed Rpm	Main-separator shaft Power Hp
150	52.62	1440	14.42	18.33	522	1.82
	21.12	1512	6.08	22.30	546	2.32
	7.14	1542	1.96	19.35	540	1.99
	42.18	1470	11.80	17.47	528	1.76
	60.00	1437	16.41	17.63	516	1.73
	18.96	1560	5.63	21.60	546	2.24
	75.48	1422	20.43	16.24	504	1.56
	20.88	1542	6.13	22.14	555	2.34
	20.10	1518	5.81	20.58	540	2.12
	44.52	1458	12.35	19.03	528	1.91
	36.30	1490	10.29	19.47	533	1.98

Table X. Feed rate, torque, speed, horsepower, motor input and generator voltage for the single-motor electrical coupling

Feed rate	Cylinder shaft			Main-separator shaft			Motor	Generator
	Torque	Speed	Power	Torque	Speed	Power	Input	Voltage
Lb/min	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp	Watts	
75	12.36	1500	3.53	13.70	537	1.40	9000	210
	17.76	1464	4.95	12.82	522	1.27	9400	210
	14.64	1503	4.19	13.70	512	1.34	9520	210
	15.50	1512	4.46	14.45	540	1.49	8480	210
	11.16	1503	3.19	13.90	537	1.42	8080	210
	25.14	1416	6.78	11.10	498	1.05	10440	204
	26.64	1380	7.00	13.55	489	1.26	12600	204
	16.98	1482	4.79	12.32	537	1.26	11000	204
	12.72	1500	3.63	13.00	534	1.32	8640	210
	22.38	1446	6.16	11.00	516	1.08	9400	206
	17.53	1471	4.91	12.68	525	1.27	9656	208
100	11.40	1488	3.23		528		10800	208
	7.20	1542	2.11		546		9000	210
	11.40	1518	3.29		537		8600	210
	26.40	1362	6.85		486		13600	207
	16.20	1476	4.55	No	525	No	11800	210
	31.80	1314	7.95	data	462	data	14200	201
	19.20	1455	5.32		516		11200	207
	10.80	1515	3.11		534		10400	212
	20.40	1461	5.67		519		10750	212
	13.80	1518	3.99		534		10400	212
	16.86	1465	4.70		519		11075	209
125	14.46	1515	4.17	15.55	531	1.57	11300	212
	32.46	1392	8.60	11.00	495	1.04	13400	210
	17.46	1494	4.96	15.55	522	1.54	12200	207
	15.66	1506	4.50	13.40	540	1.38	9800	210
	30.66	1401	8.18	12.30	501	1.17	13200	210
	28.86	1368	7.51	13.40	480	2.22	15000	202
	24.06	1500	6.86	12.85	528	1.29	11700	206
	34.86	1368	9.08	13.10	498	1.24	13500	202
	25.26	1374	6.61	15.00	480	1.37	15100	197
	33.06	1440	9.06	11.00	510	1.07	12900	207
	25.68	1436	7.02	13.31	509	1.29	12810	206

Table X. (Continued)

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Main-separator shaft Torque Lb-ft	Main-separator shaft Speed Rpm	Main-separator shaft Power Hp	Motor Input Watts	Generator Voltage
150	27.32	1287	6.69	12.60	456	1.09	16000	192
	28.26	1332	7.16	12.10	474	1.09	15200	193
	23.22	1470	6.50	13.80	519	1.36	12500	195
	29.04	1410	7.79	9.15	498	0.87	11500	206
	28.26	1344	7.23	12.45	480	1.14	14500	201
	36.78	1341	9.39	10.30	480	0.94	14500	198
	24.00	1266	5.78	12.75	447	1.08	15600	198
	37.14	1092	7.72	10.70	396	0.81	16400	195
	22.86	1251	5.44	14.00	438	1.17	15500	183
	28.62	1422	7.75	12.30	522	1.22	14500	189
	28.55	1322	7.18	12.01	471	1.08	14620	195

Table XI. Feed rate, torque, speed, power and generator voltage for the multiple-motor coupling (10-1/2-hp)

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Main-separator shaft Torque Lb-ft	Main-separator shaft Speed Rpm	Main-separator shaft Power Hp	Generator Voltage
75	25.80	1452	7.13	15.75	567	1.70	210
	15.60	1518	4.51	16.95	564	1.81	213
	9.60	1560	2.85	17.10	582	1.89	214
	19.80	1494	5.63	15.70	579	1.73	213
	27.00	1494	7.68	16.00	564	1.72	207
	12.60	1542	3.69	16.95	585	1.89	213
	18.60	1500	5.31	16.00	576	1.75	212
	16.20	1518	4.68	17.35	582	1.92	213
	19.20	1503	5.49	17.10	582	1.89	212
	30.00	1413	8.07	15.50	567	1.67	207
	19.44	1499	5.55	16.44	575	1.80	211
100	25.80	1422	6.98	13.70	561	1.46	209
	24.60	1380	6.46	13.35	561	1.43	201
	16.80	1500	4.80	15.50	579	1.71	204
	34.80	1400	9.27	13.60	558	1.44	206
	28.80	1266	6.94	14.10	540	1.45	192
	26.40	1434	7.21	16.00	570	1.74	197
	19.20	1458	5.33	15.50	564	1.66	201
	13.40	1518	3.87	15.50	582	1.72	206
	13.80	1473	3.87	15.50	564	1.66	206
	23.40	1446	6.44	14.70	564	1.58	207
	22.70	1430	6.18	14.75	564	1.58	203
125	36.72	1326	9.27	14.45	549	1.51	201
	32.82	1182	7.38	14.30	525	1.43	186
	21.96	1428	5.97	16.20	567	1.75	192
	11.94	1503	3.42	16.00	576	1.75	203
	14.22	1500	4.06	16.20	576	1.78	203
	40.98	1260	9.83	13.40	540	1.38	183
	28.56	1098	5.97	12.90	498	1.22	183
	32.82	1320	8.25	15.90	546	1.65	183
	35.94	1290	8.82	14.80	582	1.64	189
	20.82	1392	5.52	16.50	552	1.73	196
	27.68	1330	7.01	15.07	551	1.58	192

Table XI. (Continued)

Feed rate	Cylinder shaft			Main-separator shaft			Generator
	Torque	Speed	Power	Torque	Speed	Power	Voltage
Lb/min	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp	
150[1]	13.08	1515	3.77	13.80	675	1.51	212
	35.94	1356	9.28	12.25	558	1.30	201
	21.24	1443	5.83	15.15	564	1.63	205
	23.16	1443	6.36	15.15	588	1.70	200
	43.80	1128	9.40	12.25	540	1.26	175
	25.86	918	4.51	12.40	516	1.22	168
	38.22	612	4.45	13.40	522	1.33	168
	17.34	594	1.96	12.60	522	1.25	168
	27.33	1301	6.76	13.38	548	1.40	187
After jamming	29.34	1386	7.74	13.40	561	1.54	204
	25.50	1320	6.41	15.70	546	1.63	196
	19.68	1326	4.97	16.10	570	1.75	201
	18.48	1485	5.22	15.35	576	1.68	203
	36.72	1388	9.35	14.45	555	1.53	192
	25.86	1272	6.26	15.50	531	1.57	192
	26.22	1410	7.04	17.35	564	1.86	195
	37.08	1326	9.36	14.40	552	1.51	192
	20.04	1440	5.49	17.10	558	1.82	198
	12.30	1524	3.57	16.55	582	1.83	204
	25.12	1383	6.61	15.59	560	1.66	198

[1] Data obtained by continuous sampling of charts.

Table XII. Feed rate, torque, speed, power, motor input and generator voltage for the multiple-motor coupling (12-1/2-hp)

Feed rate Lb/min	Main-separator shaft Torque Lb-ft	Speed Rpm	Power Hp	Motor input[1] Watts	Hp	Generator Voltage
75	No data	564		1975	2.65	197
		602		2020	2.71	204
		570		2020	2.71	204
		570		2000	2.68	204
		558		1900	2.55	200
		570		2000	2.68	202
		564		1960	2.62	202
		552		1900	2.54	197
		570		1900	2.54	197
		579		2020	2.70	204
		570		1970	2.64	201
100	16.62	576	1.82	2025	2.71	204
	14.47	552	1.52	1900	2.55	197
	16.62	531	1.68	1800	2.41	194
	20.10	576	2.20	2040	2.74	197
	15.22	561	1.63	1975	2.65	200
	16.78	552	1.76	1875	2.51	195
	18.36	564	1.97	2020	2.71	197
	16.43	564	1.76	1980	2.65	200
	17.98	579	1.98	2050	2.75	200
	15.57	561	1.66	1950	2.61	200
	16.82	562	1.80	1962	2.63	198
125	16.64	546	1.73	1800	2.41	189
	17.98	564	1.92	1840	2.47	189
	16.91	582	1.87	2040	2.74	196
	16.11	549	1.68	2040	2.74	201
	18.52	552	1.95	1800	2.41	192
	16.64	564	1.79	1940	2.60	192
	16.11	540	1.66	2040	2.74	200
	15.30	540	1.57	1900	2.55	194
	17.18	558	1.82	1840	2.47	194
	18.25	582	2.02	2000	2.68	202
	16.97	558	1.80	1924	2.58	195

[1] Three-hp combine motor.

Table XII. (Continued)

Feed rate Lb/min	Main-separator shaft Torque Lb-ft	Main-separator shaft Speed Rpm	Main-separator shaft Power Hp	Motor input[1] Watts	Motor input[1] Hp	Generator Voltage
150	16.67	516	1.64	1700	2.28	180
	17.47	534	1.78	1800	2.41	175
	17.47	546	1.82	1900	2.55	180
	16.40	510	1.59	1600	2.15	270
	16.40	510	1.59	1700	2.28	170
	16.67	528	1.68	1775	2.38	165
	17.74	510	1.72	1700	2.28	165
	18.28	558	1.94	1920	2.57	170
	15.87	552	1.67	1800	2.41	170
	18.00	552	1.89	1840	2.47	170
	17.10	532	1.73	1774	2.38	172

Table XIII. Feed rate, cylinder torque, speed, power, motor input and generator voltage for the multiple-motor coupling (12-1/2-hp)

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Motor input[1/] Watts	Motor input[1/] Hp	Generator Voltage
75	22.20	1422	6.00	10750	14.40	197
	13.20	1500	3.77	8400	11.30	204
	10.80	1530	3.15	6080	8.20	204
	21.60	1458	6.00	6400	8.60	204
	21.60	1440	5.92	10400	13.90	200
	18.60	1494	5.29	8080	10.80	202
	25.20	1428	6.85	8950	12.00	202
	33.00	1377	8.65	11100	14.90	197
	18.00	1467	5.03	10500	14.10	197
	10.20	1527	2.96	7120	9.50	204
	19.44	1464	5.36	8778	11.77	201
100	16.14	1506	4.63	7400	9.90	204
	38.10	1368	9.92	10100	13.54	197
	30.84	1296	7.61	13000	17.43	194
	19.74	1500	5.64	9600	12.87	197
	26.34	1434	7.18	8920	11.96	200
	32.46	1368	8.45	11650	15.62	195
	19.14	1488	5.42	9000	12.06	197
	24.54	1458	6.81	8800	11.80	200
	15.54	1515	4.48	7780	10.43	200
	33.54	1401	8.94	9600	12.87	200
	25.64	1433	6.99	9585	12.85	198
125	34.20	1202	7.84	14400	19.30	189
	21.60	1437	5.91	13800	18.50	189
	15.60	1512	4.49	9600	12.86	196
	37.20	1344	9.52	8080	10.83	201
	27.60	1350	7.10	13250	17.76	192
	24.60	1446	6.77	12400	16.62	192
	21.00	1500	6.00	8750	11.73	200
	33.60	1320	8.44	10000	13.40	194
	30.00	1368	7.81	13100	17.56	194
	15.60	1515	4.50	9650	12.94	202
	26.10	1399	6.95	11303	15.15	195

[1/] 7-1/2-hp combine motor.

Table XIII. (Continued)

Feed rate Lb/min	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Motor input 1/ Watts	Motor input 1/ Hp	Generator Voltage
150	36.10	1080	7.61	14950	20.04	180
	36.10	1248	8.57	14000	18.77	175
	43.30	1278	10.53	13550	18.16	180
	25.30	762	3.67	14750	19.77	170
	26.50	960	4.84	14800	19.84	170
	40.30	1200	9.20	14800	19.84	165
	26.50	1212	6.11	14800	19.84	165
	34.30	1338	8.73	13600	18.23	170
	37.90	1128	8.14	14700	19.71	170
	29.50	1212	6.81	14400	19.30	170
	33.58	1142	7.30	14435	19.35	172

Table XIV. Time analysis of cylinder torque, speed and power for the pto coupling

Time[1]	100 Lb-minute			150 Lb-minute		
Sec	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp
1	16.80	1530	4.89	18.60	1500	5.31
2	36.60	1488	10.37	13.20	1536	3.86
3	24.60	1512	7.08	7.80	1530	2.27
4	43.80	1458	12.15	12.60	1500	3.60
5	15.60	1560	4.63	44.40	1458	12.32
6	11.40	1530	3.32	45.60	1446	12.55
7	30.00	1494	8.53	12.00	1560	3.56
8	19.80	1540	5.80	28.20	1530	8.21
9	12.60	1560	3.74	40.80	1458	11.32
10	33.50	1500	9.56	58.80	1440	16.10
11	48.00	1470	13.43	16.80	1560	4.99
12	24.60	1536	7.19	33.50	1470	9.37
13	17.40	1554	5.15	67.80	1386	17.89
14	10.20	1530	2.97	10.80	1560	3.21
15	14.40	1524	4.18	15.60	1500	4.45
16	46.20	1470	12.92	43.20	1470	12.09
17	33.30	1524	9.66	12.00	1560	3.56
18	21.00	1530	6.12	45.00	1452	12.44
19	13.80	1560	4.10	67.20	1416	18.11
20	-	-	-	23.40	1518	6.76

[1] Time arbitrarily started at one second.

Table XV. Time analysis of cylinder torque, speed and power for the multiple-motor coupling (12-1/2-hp)

Time[1/]	100 Lb-minute			150 Lb-minute		
	Torque	Speed	Power	Torque	Speed	Power
Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
1	10.14	1548	2.99	6.72	1500	1.92
2	10.14	1524	2.94	30.12	1380	7.91
3	11.94	1500	3.41	31.32	1332	7.94
4	27.54	1410	7.39	40.32	1050	8.06
5	16.74	1500	4.78	27.72	1110	5.75
6	27.54	1410	7.37	36.72	1104	7.72
7	16.14	1494	4.59	31.32	1200	7.15
8	24.54	1470	6.87	33.72	1278	8.20
9	40.14	1290	9.86	50.52	1188	11.42
10	27.54	1320	6.92	25.32	750	3.61
11	23.94	1500	6.83	24.12	942	4.32
12	26.34	1440	7.22	31.92	950	5.77
13	31.74	1380	8.34	36.12	1020	7.01
14	23.94	1410	6.42	29.52	1200	6.74
15	16.74	1500	4.78	40.32	1326	10.17
16	23.94	1446	6.59	36.72	1134	7.93
17	14.94	1530	4.35	30.72	1200	7.02
18	32.94	1434	9.00	24.12	1410	6.47
19	40.14	1080	8.25	38.52	1320	9.68
20	27.54	1254	6.57	23.52	1428	6.39

[1/] Time arbitrarily started at one second.

Table XVI. Time analysis of cylinder torque, speed and power for the single-motor coupling

Time[1/]	100 Lb-minute			150 Lb-minute		
	Torque	Speed	Power	Torque	Speed	Power
Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
1	6.00	1524	1.74	8.40	1512	2.42
2	18.60	1488	5.27	33.00	1356	8.52
3	18.60	1410	4.99	29.40	1200	6.71
4	23.40	1452	6.47	27.00	1290	6.63
5	24.60	1380	6.46	28.20	1320	7.08
6	15.60	1500	4.45	19.20	1458	5.33
7	19.80	1458	5.49	19.20	1464	5.35
8	9.60	1524	2.78	31.20	1320	7.84
9	8.40	1536	2.46	28.80	1350	7.40
10	11.40	1500	3.25	39.00	1290	9.58
11	31.20	1344	7.98	25.20	1278	6.13
12	19.80	1470	5.54	42.00	1158	9.26
13	32.40	1404	8.66	24.60	1146	5.37
14	21.60	1326	5.45	21.00	1398	5.59
16				32.40	1374	8.47
17				28.20	1314	7.05
18				18.60	1452	5.14
19				22.80	1470	6.38
20				30.60	1248	7.27
21				19.80	1434	5.40

[1/] Time arbitrarily started at one second.

Appendix D: Slug Study Data

Table XVII. Performance of the pto and the electrical couplings during high momentary overloads[1/]

Coupling	Time	Cylinder shaft			Pickup and canvas shaft		
		Torque	Speed	Power	Torque	Speed	Power
	Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
Pto	1	12.00	1440	3.29	4.50	870	0.75
	2	7.20	1440	1.97	4.66	870	0.77
	3	18.60	1410	4.99	4.66	858	0.76
	4	45.60	1380	11.98	4.89	846	0.79
	5	30.00	1410	8.05	5.11	858	0.83
	6	37.20	1410	9.98	4.44	852	0.72
	7	39.60	1410	10.63	4.55	858	0.74
	8	27.00	1440	7.40	4.89	870	0.81
	1	15.00	1440	4.11	4.94	858	0.81
	2	27.60	1410	7.41	5.11	858	0.83
	3	33.00	1422	8.93	5.55	864	0.91
	4	39.00	1398	10.38	4.72	846	0.76
	5	43.80	1386	11.55	5.16	858	0.84
	6	36.60	1422	9.91	4.39	858	0.72
	7	21.00	1434	5.73	4.61	870	0.76
	8	7.20	1446	1.98	4.61	870	0.76
	1	21.00	1410	5.64	5.22	846	0.84
	2	40.80	1392	10.81	4.77	858	0.78
	3	43.80	1380	11.50	4.77	840	0.76
	4	15.60	1440	4.28	5.22	870	0.86
	5	22.20	1410	5.96	4.61	858	0.75
	6	29.40	1410	7.89	4.55	858	0.74
	7	9.60	1470	2.69	4.39	882	0.74
	8	12.00	1470	3.36	3.84	894	0.65

[1/]Crop: windrowed oats.
Feed rate: 50 pounds per minute per windrow.
Slug density: 6 windrows.
Slug length: 10 feet.

Table XVII. (Continued)

Coupling	Time	Cylinder shaft			Pickup and canvas shaft		
		Torque	Speed	Power	Torque	Speed	Power
	Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
Single-motor	1	11.40	1470	3.19	5.13	882	0.86
	2	24.00	1422	6.50	5.30	864	0.87
	3	35.40	1350	9.10	5.54	816	0.86
	4	36.60	1320	9.04	5.54	804	0.85
	5	38.40	1302	9.52	5.13	786	0.77
	6	42.00	1272	10.17	5.30	780	0.79
	7	54.60	1158	12.03	4.36	720	0.60
	8	31.20	1008	5.99	4.20	618	0.49
	9	33.50	1158	7.38	4.64	702	0.62
	10	27.60	1380	7.25	4.69	840	0.75
	11	18.00	1470	5.04	4.64	888	0.78
	1	12.00	1440	3.29	4.91	870	0.81
	2	15.00	1422	4.06	5.41	870	0.90
	3	41.40	1260	9.93	4.64	762	0.67
	4	42.00	1140	9.11	4.80	690	0.63
	5	36.00	1014	6.95	4.80	630	0.58
	6	32.40	1062	6.55	4.80	648	0.59
	7	33.60	1080	6.91	4.64	660	0.58
	8	33.00	1158	7.27	4.80	690	0.63
	9	36.00	1212	8.30	4.20	750	0.60
	10	24.00	1350	6.17	4.69	810	0.72
	11	16.20	1458	4.50	4.25	882	0.71
	12	12.00	1470	3.36	4.47	870	0.74
	1	19.80	1440	5.43	4.91	870	0.81
	2	17.40	1440	4.77	5.03	870	0.83
	3	21.60	1434	5.90	5.13	864	0.84
	4	35.40	1350	9.10	5.03	816	0.79
	5	40.20	1230	9.41	5.35	750	0.76
	6	21.00	960	3.84	5.03	570	0.55
	7	18.00	990	3.39	5.30	570	0.58
	8	22.20	990	4.18	4.64	600	0.53
	9	21.00	990	3.96	5.03	600	0.57
	10	20.40	1008	3.91	4.69	618	0.55
	11	15.00	1038	2.96	4.64	642	0.57
	12	10.20	1290	2.50	4.80	780	0.71

Table XVII. (Continued)

Coupling	Time	Cylinder shaft			Pickup and canvas shaft		
		Torque	Speed	Power	Torque	Speed	Power
	Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
Multiple-motor (10-1/2-hp)	1	12.90	1440	3.53			
	2	20.10	1416	5.41			
	3	34.80	1338	8.85			
	4	39.90	1278	9.70			
	5	29.10	1350	7.48			
	6	31.50	1380	8.25			
	7	29.70	1380	7.80			
	8	34.50	1290	9.45			
	9	24.90	1398	6.70			
	10	18.30	1440	5.00			
	1	11.10	1470	3.11			
	2	24.30	1380	6.38			
	3	27.90	1404	7.45			
	4	33.90	1314	8.48			
	5	32.10	1326	8.08			
	6	24.90	1434	6.79			
	7	26.10	1398	6.94			
	8	27.80	1368	7.24			
	9	22.50	1440	6.16			

Table XVIII. Performance of the pto and the electrical couplings during high momentary overload[1]

Coupling	Time	Cylinder shaft			Main-separator shaft		
	Sec	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp
Pto	1	19.80	1440	5.42	17.70	552	1.85
	2	30.60	1440	8.38	17.70	558	1.88
	3	30.00	1452	8.29	18.25	564	1.96
	4	35.40	1440	9.70	17.70	552	1.85
	5	46.20	1410	12.35	18.25	540	1.87
	6	54.20	1410	14.50	18.80	540	1.93
	7	40.80	1440	11.20	19.00	552	1.99
	8	34.80	1440	9.54	19.85	540	2.02
	9	42.00	1410	11.25	19.85	540	2.02
Multiple motor (12-1/2-	1	13.80	1500	3.94	19.00	510	1.84
	2	33.50	1380	8.79	17.40	504	1.66
	3	31.20	1368	8.12	19.50	480	1.78
	4	38.40	1314	9.61	18.20	480	1.66
	5	34.80	1326	8.78	20.01	480	1.83
	6	45.00	1290	11.00	20.01	480	1.83
	7	38.40	1110	8.12	19.80	450	1.69
	8	32.40	1140	7.03	20.60	468	1.83
	9	28.80	1300	7.12	20.30	509	1.96
	1	11.40	1470	3.18	20.60	486	1.90
	2	39.00	1236	9.18	19.50	480	1.78
	3	36.60	1158	8.06	20.20	474	1.82
	4	40.20	1158	8.85	20.30	468	1.80
	5	36.60	1068	7.42	21.40	456	1.85
	6	33.60	1026	6.55	21.20	456	1.83
	7	38.40	1002	7.30	21.20	462	1.86
	8	33.60	960	6.14	21.20	468	1.88
	9	30.60	1140	6.64	22.30	462	2.00
	10	25.20	1386	6.58	23.30	480	2.12

[1] Crop: windrowed oats.
Feed rate: 50 pounds per minute per windrow.
Slug density: 8 windrows.
Slug length: 10 feet.

Table XVIII. (Continued)

Coupling	Time	Cylinder shaft			Main-separator shaft		
		Torque	Speed	Power	Torque	Speed	Power
	Sec	Lb-ft	Rpm	Hp	Lb-ft	Rpm	Hp
Multiple motor (10-1/2-hp)	1	17.10	1470	4.79			
	2	22.50	1440	6.15			
	3	36.90	1380	9.69			
	4	44.70	1248	10.60			
	5	41.70	1164	9.24		No data	
	6	34.50	1140	7.48			
	7	42.90	1050	8.55			
	8	35.70	1062	7.22			
	9	29.70	1254	7.08			
	1	17.10	1452	5.02			
	2	28.50	1386	7.52			
	3	37.50	1320	9.42			
	4	44.70	1230	10.42			
	5	47.10	1200	10.72			
	6	41.70	1200	9.50			
	7	41.70	1218	9.65			
	8	43.50	1200	9.89			
	9	33.90	1333	8.62			
	10	23.10	1440	6.32			

Appendix E: Load-Analysis and Performance Data in Windrowed Wheat

Table IXX. Performance of the pto and the electrical couplings[1/]

Coupling	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Shaft Torque Lb-ft	Shaft Speed Rpm	Shaft Power Hp	Motor input Hp	
				Main-separator				
Pto	21.78	1590	6.60	16.21	558	1.72		
	26.58	1554	7.86	15.95	564	1.71		
	29.58	1560	8.78	17.29	552	1.82		
	19.98	1620	6.16	17.55	558	1.86		
	27.78	1590	8.41	16.48	570	1.79		
	19.98	1620	6.16	16.75	558	1.78		
	14.58	1620	4.96	17.02	576	1.87		
	15.78	1596	4.79	17.55	558	1.86		
	36.18	1548	10.66	17.82	540	1.83		
	32.58	1596	9.90	17.92	570	1.88		
	24.38	1589	7.37	17.00	560	1.81		
				Pickup attachment			7-1/2-hp	
Single motor	19.98	1500	5.70	5.13	840	0.82	14.60	
	13.98	1548	4.12	5.02	858	0.82	14.35	
	12.18	1560	3.62	5.91	866	0.97	12.71	
	34.98	1332	8.87	4.03	750	0.58	17.85	
	22.98	1368	5.98	5.02	774	0.74	19.70	
	22.98	1440	6.30	4.80	810	0.74	18.10	
	22.38	1470	6.26	5.02	840	0.80	17.00	
	29.58	1410	7.94	4.25	798	0.65	18.35	
	18.18	1500	5.19	5.52	840	0.88	16.09	
	28.38	1446	7.81	5.24	819	0.81	17.05	
	22.56	1457	6.26	4.99	819	0.78	16.58	
								2-hp
Multiple motor (9-1/2-hp)	23.70	1488	6.71				14.75	1.31
	20.10	1518	5.81				12.60	1.31
	15.30	1560	4.54		No data		10.98	1.31
	21.30	1530	6.20				11.79	1.31
	26.10	1512	7.51				12.25	1.31
	33.30	1512	9.58				13.82	1.34
	25.50	1452	7.05				15.20	1.30
	44.10	1440	12.09				17.20	1.31
	26.70	1410	7.17				16.40	1.31
	26.70	1470	7.47				14.10	1.31
	26.28	1489	7.44				13.91	1.31

[1/]Crop: windrowed wheat.
Feed rate: 130 pounds per minute.

Table IXX. (Continued)

Coupling	Cylinder shaft			Shaft			Motor input	
	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp	Hp	
				Pickup attachment			7-1/2-hp	
Multiple motor (10-1/2-hp)	37.80	1332	9.58	4.97	744	0.70	12.86	
	27.50	1344	7.03	5.19	720	0.71	18.77	
	31.20	1458	8.66	5.41	840	0.87	19.57	
	23.40	1524	6.79	5.41	858	0.83	17.43	
	21.60	1560	6.41	5.30	888	0.90	13.67	
	22.20	1548	6.54	5.52	888	0.93	12.06	
	18.60	1554	5.50	5.08	858	0.83	11.80	
	37.20	1392	9.86	4.42	804	0.67	12.06	
	26.40	1500	7.54	5.10	846	0.84	17.69	
	21.60	1530	6.29	4.64	870	0.77	13.40	
	26.75	1474	7.50	5.11	832	0.81	14.93	
				Main-separator				3-hp
Multiple motor (12-1/2-hp)	39.42	1386	10.40	12.86	474	1.16	17.16	1.88
	29.82	1440	8.17	14.74	480	1.35	16.09	1.93
	29.22	1506	8.38	14.20	498	1.35	14.61	2.01
	38.22	1476	10.74	15.28	492	1.43	15.15	1.88
	37.62	1242	8.89	13.67	470	1.22	18.77	1.74
	26.22	1434	7.16	15.54	480	1.42	16.42	2.11
	22.22	1554	6.69	15.28	498	1.45	13.27	2.14
	28.62	1500	8.17	14.74	486	1.36	13.14	2.09
	24.42	1500	6.97	15.28	480	1.40	12.06	2.04
	27.42	1470	7.67	16.35	480	1.49	13.40	2.14
	30.36	1451	8.38	14.79	483	1.36	15.01	2.00

Table XX. Time analysis of cylinder torque, speed and power for the pto coupling[1/]

Time Sec	Torque Lb-ft	Speed Rpm	Power Hp
1	21.18	1590	6.41
2	18.78	1590	5.69
3	18.18	1620	5.61
4	28.98	1560	8.60
5	29.58	1590	8.95
6	26.58	1590	8.04
7	19.38	1620	5.98
8	19.38	1590	5.86
9	19.98	1572	5.98
10	34.38	1560	10.21
11	27.78	1590	8.41
12	17.58	1620	5.42
13	24.78	1590	7.50
14	22.40	1590	6.78
15	16.70	1632	5.18
16	15.20	1620	4.69
17	25.38	1578	5.72
18	30.78	1560	9.13
19	33.18	1590	10.04
20	18.18	1626	5.63
21	11.58	1620	3.57
22	13.40	1590	4.06
23	16.38	1590	4.96
24	21.18	1614	6.51
25	12.18	1626	3.77
26	12.18	1620	3.76
27	12.80	1620	3.95
28	12.18	1620	3.76
29	52.38	1500	14.95
30	36.80	1620	11.35
31	46.40	1560	13.78
32	26.00	1590	7.87
33	19.98	1632	6.21
34	15.78	1620	4.87
35	32.58	1578	9.79
36	21.78	1620	6.72

[1/] Crop: windrowed wheat.
Feed rate: 130 pounds per minute.

Appendix F: Load-Analysis and Performance Data in Rowed Soybeans

Table XXI. Performance of the pto and the electrical couplings[1]

Coupling	Cylinder shaft			Shaft		
	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp
				Main-separator		
Multiple motor (12-1/2-hp)	86.4	450	7.41	19.56	588	2.19
	72.6	450	6.22	20.10	570	2.18
	96.6	420	7.72	17.42	564	1.57
	127.8	360	8.76	16.88	522	1.68
	95.4	480	8.72	21.71	636	2.63
	101.4	480	9.26	21.71	630	2.60
	48.0	468	4.28	19.83	630	2.38
	36.6	510	3.55	21.98	648	2.71
	52.2	510	5.07	22.51	648	2.78
	59.4	510	5.77	20.37	648	2.51
	72.6	463	6.84	20.21	611	2.35
Multiple motor (10-1/2-hp)	60.0	510	5.82	18.76	630	2.25
	150.0	462	13.19	18.22	630	2.18
	98.4	486	9.10	19.30	642	2.36
	131.4	456	11.40	18.22	630	2.18
	94.8	480	8.66	19.56	630	2.35
	54.6	510	5.30	20.37	648	2.51
	34.8	510	3.38	19.03	642	2.33
	33.0	510	3.20	20.10	654	2.50
	30.6	510	2.97	18.49	660	2.32
	33.0	516	3.24	18.49	660	2.32
	72.6	495	6.83	19.05	643	2.33
				Knife and canvas		
Single motor	116.4	450	9.97	9.83	840	1.57
	106.2	390	7.88	10.49	750	1.50
	93.0	468	8.28	10.05	900	1.72
	66.0	492	6.18	10.60	930	1.88
	63.0	492	5.90	10.05	930	1.78
	131.4	402	10.05	9.38	780	1.39
	47.4	492	4.44	11.59	930	2.05
	35.4	510	3.44	9.94	930	1.76
	27.0	510	2.62	10.05	960	1.84
	19.2	510	1.86	9.83	930	1.74
	70.5	472	6.32	10.18	888	1.72

[1]Crop: soybeans.

Table XXI. (Continued)

Coupling	Cylinder shaft Torque Lb-ft	Cylinder shaft Speed Rpm	Cylinder shaft Power Hp	Shaft Torque Lb-ft	Shaft Speed Rpm	Shaft Power Hp
				Knife and canvas		
Pto	64.2	510	6.23	9.16	960	1.67
	72.6	498	6.88	9.94	960	1.75
	73.2	498	6.94	9.94	960	1.82
	57.0	498	5.40	9.94	900	1.70
	55.8	504	5.35	10.05	900	1.72
	54.6	498	5.18	10.27	900	1.76
	60.0	504	5.76	10.27	900	1.76
	52.8	498	5.00	9.16	978	1.71
	72.0	498	6.82	9.60	900	1.64
	97.8	492	9.16	10.49	900	1.80
	66.0	500	6.28	9.85	926	1.74

Table XXII. Time analysis of cylinder torque, speed and power for the pto and the multiple-motor coupling during a short overload period[1]

Time[2]	Pto			Multiple motor (12-1/2-hp)		
Sec	Torque Lb-ft	Speed Rpm	Power Hp	Torque Lb-ft	Speed Rpm	Power Hp
1	40.2	510	3.90	51.6	504	4.95
2	75.0	498	7.12	92.4	486	8.56
3	124.8	486	11.45	109.2	408	8.45
4	79.2	510	7.67	73.2	468	6.50
5	61.8	510	5.88	40.8	522	4.04
6	33.0	510	3.70			

[1]Crop: soybeans.

[2]Time arbitrarily started at one second.

Appendix G: Drive Efficiency Data

Table XXIII. Cylinder drive efficiency for different cylinder loads

Cylinder shaft			Motor data[1]			
Torque Lb-ft	Speed Rpm	Power Hp	Input Watts	Input Hp	Output Hp	Drive eff.%
39.72	1260	9.50	12000	16.08	13.48	70.5
39.30	1260	9.41	12000	16.08	13.48	69.8
40.80	1260	9.68	11800	15.82	13.30	72.8
17.10	1320	6.77	6000	8.04	7.32	62.0
83.10	726	11.52	14100	18.90	15.50	74.4
70.00	750	9.98	12100	16.22	13.57	73.6
48.80	780	7.24	9000	12.06	10.55	68.6
35.60	810	5.47	7200	9.65	8.65	63.4
33.20	804	5.07	7000	9.38	8.45	60.0
32.30	816	5.01	6800	9.12	8.23	60.9
22.60	828	3.55	5200	6.97	6.40	55.5
21.80	828	3.43	5100	6.84	6.26	54.8
5.58	852	0.90	2800	3.75	3.35	26.8
80.60	426	6.52	8200	10.99	9.72	67.0
67.40	432	5.51	7100	9.52	8.56	64.4
47.00	444	3.97	5480	7.35	6.72	59.1
18.80	456	1.63	3600	4.83	4.40	37.1
6.75	464	0.60	1900	2.55	2.20	27.2

[1] Motor output was obtained from the plot of watts input vs. horsepower output for the motor. See Figure 42 Appendix B.